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PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
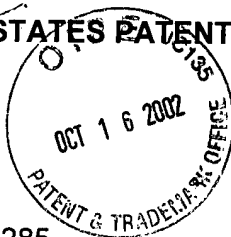
In the Application of:

JENNIE BIH-JIEN SHEN

CASE NO.: BB1137 US CPA

APPLICATION NO.: 09/326,285

GROUP ART UNIT: 1634

FILED: JUNE 7, 1999

EXAMINER: JULIET C. EINSMANN

FOR: GENES FOR DESATURASES TO ALTER
LIPID PROFILES IN CORN

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Declaration of Dr. Thomas E. Sauber Pursuant to 37 CFR §1.132

I, Thomas E. Sauber, am a citizen of the United States of America, residing at 5744 Wentworth Dr., Johnston, Iowa 50131, and I declare as follows:

1. I am a graduate of the University of Minnesota with a B.S. degree granted in 1979 in Biological Sciences. I received an M.S. in Animal Nutrition in 1994, and a Ph.D. in Animal Nutrition in 1996 from Iowa State University (awarded the National Pork Producers Council Innovative Research Award and the Iowa State University Research Excellence Award). Since 1996 I have been employed by Archer, Daniels, Midland (1996), Pioneer Hi-Bred International (1996-1997), Optimum Quality Grains (a subsidiary of E. I. du Pont de Nemours and Company, 1998-1999), DuPont Specialty Grains (2000-2001), and Pioneer Hi-Bred International ((a subsidiary of E. I. du Pont de Nemours and Company, 2001-present) directing and conducting research in developing novel feed for livestock, and feeding studies of livestock. I have been actively engaged in the pork industry for over 20 years. I was a partner in a feed formulation, manufacturing and distribution business in Northwest Iowa (1982 to 1990). During that time we manufactured feed for pork, beef and dairy customers. My responsibilities included ingredient purchasing, feed formulation and contract management. From 1996 to present I have been in a variety of feed related technical and business roles for Pioneer Hi-Bred International and the DuPont Company. I have extensive experience in animal feeding studies, commercial grain production, nutritional studies on animal feed, and sales and distribution of animal feed.

2. I have reviewed the Office Action dated 21 March, 2002. I understand that this declaration is being submitted to address the concerns raised with respect to enablement, in particular, the concern that "carcass quality improving amount" and "it is highly unpredictable as to how feeding regimes will effect the carcass quality of animals" are not well understood terms or reproducible processes known to one skilled in the art. Furthermore, it is stated on page 5 of the Office Action that due "to the broad nature of the claims, the lack of guidance in the specification or in the prior art, the high level of unpredictability with regard to the effects of feeding regimes on animal carcass quality, the lack of working examples, and the high level of experimentation necessary to determine the methodology necessary to practice the claimed invention, it is concluded that undue experimentation would be required to practice the claimed invention." The data and literature presented herein demonstrates that carcass quality can be reproducibly improved through feeding regimens, and particularly, that the feeding of high-oleic grain can improve carcass quality.

3. Submitted herewith is a copy of an index from the Optimum® High Oil Corn Technical Information and copies of a number of the articles mentioned therein. Also included are copies of some articles from Nutritional Insights which appears on the Pioneer Hi-Bred International, Inc. web site and a copy of a May/June 1999 article from Feed Lot, Vol. VII, No. 3, appearing on its website regarding the use of Optimum High Oil Corn to improve performance and carcass quality, specifically, in cattle beef.

The Nutritional Insights article entitled "Benefits of Feeding Optimum® High Oil Corn To Finishing Beef Cattle Research Studies to Determine Feeding Value (Summary) indicates that Optimum® High Oil Corn can effectively replace 100% of typical corn and up to 3% added fat in finishing beef cattle diets. Cattle fed with this high oil corn, according to the studies, generally produced carcasses having a higher% choice or better than those fed typical corn without added fat.

Copies of the articles discussing the Colorado study, Idaho Study and the Iowa Study are included herewith.

The articles describe the feeding trials and how they were conducted. Carcass quality data is presented on page 2.

The University of Idaho feeding trial demonstrated that feeding high oil corn improved the marbling scores and carcass quality grades of finishing beef steers compared to those fed typical corn. The conditions for the feeding trial are set forth on the first page and Carcass Quality data is set forth in Table 5. It is stated on page 1 that the "Idaho trial used 60 head of yearling Angus-cross steers that averaged 906 pounds and were fed in an 84-day finishing trial. Three treatments of 20 head each

were evaluated as: 1) control (typical corn), 2) high oil corn, and 3) high oil corn fed at a level isocaloric to control (increased roughage level). All corn was dry rolled and fed in a total mixed ration. The rations were iso-nitrogenous by adjusting the urea level in the diet. The high oil corn averaged 7.04% while the normal corn averaged 4.86% oil on a dry matter basis. Steers were fed to appetite twice daily using individual electronic gates and were implanted with Synovex-SO at the start of the trial. . . ."

The Iowa study reported that there "were no effects of feeding high oil corn on carcass characteristics, except there were more choice carcasses from the steers fed high oil corn as compared with the control."

The DuPont Specialty Grains articles present feeding trials involving pork, beef and poultry. The feeding regimens are set forth and are fairly detailed. The studies took place in the 1991-1999 time frame.

Clearly the information set forth in these articles shows that those skilled in the art know how to adjust feeding regimens and that to the extent any experimentation is needed it is not undue. The wealth of information presented in these articles shows how different animals are fed, what they are fed, how the diets are adjusted and how the improvement in carcass quality is assessed.

4. Five additional references are included to demonstrate that feeding studies involving pigs show a clear, reproducible, and rapid alteration of carcass quality when oil compositions of the feed are modified (Whittington et al. (1986) *J.Sci.Food Agric.* 37:753-761; Myer et al. (1992) *J.Anim.Sci.* 70:3734-3741; Hansen (2001) *Proceedings of the Carolina Nutrition Conference.* Raleigh, NC; Madsen et al. (1992) *Anim. Sci.* 42:220-225; and Gatlin et al. (2002) *J. Anim. Sci.* 80:1606-1615). Applicants have selected these five publications as a representative sample of 29 publications that can be made available to the examiner if additional information is required.

Whittington et al. conclude that lowering the amount of linoleic acid, an 18:2 polyunsaturated fatty acid, in the feed results in a lowering of polyunsaturated fatty acids (PUFAs) in the fat of the pigs. This improves the carcass quality of the animals by increasing the firmness of the pork fat. Myer et al. concluded that pigs fed a high oleic (18:1 monounsaturated fatty acid) diet , that was low in PUFAs, resulted in carcasses with increased saturated fat and lower PUFAs. Hansen concludes that dietary fat is the primary factor in swine feed that determines carcass quality characteristics. Furthermore, short-term feeding that results in carcass quality change is tightly linked to fat type or level of the feed. Hansen claims that these types of results are clear and predictable. Madsen et al. review the relationship of oil

composition in pig feed to various parameters of carcass quality. The general conclusion, relevant to the present invention, is that high levels of PUFAs increases fat softness (an undesirable trait) and shortens shelf-life (the fat goes rancid faster than more saturated fat). Gatlin et al. further refine the composition of the feed to increase mono-unsaturated and lower PUFAs, which results in improved fat firmness in as little as 6-8 weeks of feeding.

Clearly the information set forth in these articles shows that those skilled in the art know how to adjust feeding regimens and that to the extent any experimentation is needed it is not undue. The wealth of information presented in these articles shows how different animals are fed, what they are fed, how the diets are adjusted and how the improvement in carcass quality is assessed.

5. It is possible to show that dietary fat and pork carcass quality are related by plotting the iodine values (IV, an indicator of the degree of fat saturation or hardness) of pork fat taken from animals fed varying dietary feed compositions. Data presented in the Madsen reference (pork IV – 47.1 + (0.14 x IVP))and data from a separate study (Boyd (1995) "Effect of dietary linoleic acid intake on body fat deposition of linoleic acid in growing pigs" PIC USA Franklin, KY; pork IV = 52.4 + (0.315 x IVP)) were plotted below and both show a clear correlation between dietary fat and pork carcass quality. The fact that the two unrelated studies both show approximately parallel responses is taken as further evidence that feeding and resulting carcass quality are reproducible phenomena. Trial data points on the graph below represent combined results from feeding studies of Trial COSW11200100 (typical corn, 60% high oleic corn, and combinations of corn oil and high oleic sunflower oil were used to simulate the transgenic corn oil composition) and Trial COSW01SWG003 (typical corn, 60% high oleic corn and 80% high oleic soybeans fed individually and in combination) that I conducted in 2000 and 2001 . These results are consistent with previous results and demonstrate that high oleic corn would be expected to improve the carcass quality of feed animals.

Relationship between dietary IV and pork carcass IV
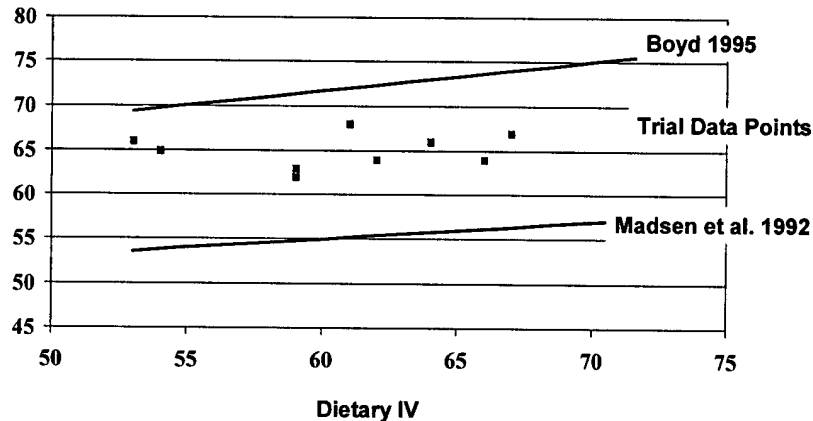
6. Regarding Machev et al. which is described on page 4 of the Office Action as disclosing that "completely replacing maize with barley in animal feed had no significant effect on the slaughter and commercial value of pigs (ABSTRACT, p.26). . . .", it is noted that this article does not appear to disclose the composition of the "grower mixture" and "finisher mixture" used in the feeding studies except to say that grain is 74% and 80% (respectively) of the feed. It is not clear what constituted the remainder of the feed. Given this, it is not appropriate to conclude anything since the unknown components may have contributed to the overall outcome. It is possible that if one of ordinary skill in the art was aware of all of the composition of the feed it may have been understandable as to how the feeding regimen affected carcass quality.

In addition, the examiner states that the replacement of barley for corn in the animal feed of the Machev article would be expected to have a greater effect on carcass quality than the replacement of high-oleic corn (of the present invention) for wild-type corn. As shown in the table below the composition of high oleic corn to typical corn is significantly different from both typical corn and barley, particularly with respect to PUFA content, which as stated above, has a demonstrable effect on lowering carcass quality. This is further shown by the iodine value, which is an indicator of oil saturation or hardness. Therefore, it is believed that one would expect a greater effect on carcass quality from substituting the grain of the present invention than replacing corn with barley.

% Fatty Acid	Barley[1]	Typical Corn[2]	High Oleic Corn[3]
Palmitic	21-29	11	4
Stearic	0.6-1.8	2	5
Oleic	10-16	24	81
Linoleic	52-58	62	9
Linolenic	5-7	1	1
Saturated	22-31	13	9
Mono-unsaturated	10-16	24	81
PUFA	57-65	64	10
Iodine Value	122	131	88

[1] Welch, R.W. 1979. Genotypic variation in oil and protein in barley grain. J. Sci Food and Agric. 29:953-958
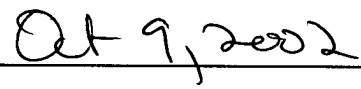[2] Corn: Chemistry and Technology. American Association of Cereal Chemists. 1987
[3] Expected fatty acid composition of transgenic high oleic corn grain

Thus, it is respectfully submitted that the determination of such factors does not involve undue experimentation and is well within the ordinary level of skill in the art at the time the invention was made.

6. Further, I declare that all the statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Thomas E. Sauber

Oct 9, 2002

Date

Effect of Feeding High-Oleic-Acid Peanuts to Growing-Finishing Swine on Resulting Carcass Fatty Acid Profile and on Carcass and Meat Quality Characteristics[1,2]

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ABSTRACT: A high-oleic-acid peanut breeding line was used in a study designed to determine the effects of feeding swine diets containing elevated levels of monounsaturated fatty acids as a means to increase the level of monounsaturates and total unsaturates in the resulting carcass fat. Forty-eight pigs were allotted to four treatments that consisted of corn-soybean meal diets that contained 1) high-oleic peanuts (HOP), 2) regular commercial peanuts (RP), or 3) canola oil (CO), each added at a dietary level to provide 10% added fat/oil, and 4) a control diet with no added fat/oil. The oil of HOP averaged 75% oleic acid vs 80% for CO and 53% for RP. The pigs were fed the experimental diets from 33 to 102 kg BW, after which all pigs were slaughtered. All three dietary oil sources resulted in increases ($P < .01$) of monounsaturates in the backfat; the HOP diet resulted in the greatest increase (32% greater than control). Both CO and RP increased ($P < .01$) the level of polyunsaturates by nearly twofold; resulted in a small decrease. Total unsaturates increased ($P < .01$) by 24, 24, and 27% for HOP and CO treatments, respectively, over the tained from the control treatment. Carcass fat softer/oiler ($P < .05$) from pigs fed CO and diets, but not from those fed HOP diets, compared with carcass fat of pigs fed the control Dietary fat/oil source had no effect ($P > .)$ other carcass compositional traits and various meat quality attributes. Dietary fat/oil source had no effect ($P > .05$) on taste panel evaluation of broiled loin chops and fried bacon; however high incidence of off-flavor was noted for from pigs fed CO and to a lesser extent from fed RP, but not from HOP or control pigs. The increased the level of unsaturates in pork fat there were essentially no detrimental effect carcass and meat quality characteristics.

Key Words: Pigs, Peanuts, Peanut Oil, Oleic Acid, Fatty Acids

J. Anim. Sci. 1992. 70:373

Introduction

The level of saturated fat in pork fat can be readily reduced by the inclusion of an unsaturated fat source in the pig's diet. Much of the previous research with pork fat modification used containing fat sources high in polyunsat fatty acids (Wahlstrom et al., 1971; Shelley 1975; Hartman et al., 1985). There has be increased interest in the use of vegetable o in monounsaturated fatty acids, such as oil, in swine diets (St. John et al., 1987; Rhe 1988a; Miller et al., 1990; Myer et al., 1992 interest is due to the favorable publicit monounsaturated fats have received in rej human health (Mattson and Grundy, Grundy, 1986).

Although canola oil (CO) is a good so monounsaturated fatty acids, it also con relatively high level of polyunsaturate

acids, in particular linolenic acid. These polyunsaturated fatty acids have been implicated as the cause of offflavors reported for cooked pork products from CO-fed pigs (Rhee et al., 1988a,b; Miller et al., 1990; Shackelford et al., 1990a,b). Vegetable oils higher than CO in monounsaturated fatty acids and lower in polyunsaturated fatty acids, such as high-oleic sunflower oil, are ac r available. Use of these oils in pork fat modification studies has been encouraging (Miller et al., 1990; Rhee and Ziprin, 1990; Shackelford et al., 1990a,b; Ziprin et al., 1990). These high-oleic vegetable oils, however, still contain 8 to 15% polyunsaturated fatty acids.

Another potential high-oleic-acid vegetable oil is that derived from a line of high-oleic-acid peanuts (HOP). The oil in these peanuts has been found to contain a very high level of monounsaturated fatty ac ic, mainly oleic acid, and a very low level of polyunsaturated fatty acids (Norden et al., 1987). The objective of this study was to determine the effects of adding HOP, commercial (regular) peanuts (RP), or CO to growing-finishing swine diets, to provide 10% added fat/oil, on resulting carcass and meat quality characteristics and carcass fat firmness and fatty acid profile.

Materials and Methods

High-oleic-acid peanuts were used as the source of oil instead of the extracted oil. This peanut type is in early development and limited quantities were available, not enough for extraction at a commercial facility. For comparison, a commercially available variety of peanuts was also used in a similar manner in a separate treatment.

The feeding trial was conducted at the Marianna North Florida Research and Education Center Swine Unit, located in northwest Florida. Forty-eight crossbred pigs with an average initial weight of 33 kg were divided among four dietary treatments. The treatments were corn-soybean meal-based diets that contained HOP, RP, or CO, each to provide 10% added fat/oil, and diets that contained no added fat/oil (control).

Pigs were assigned by sex and initial weight into pens of four pigs each, and each pen was assigned at random to one of the above four dietary treatments within each of three replicates. Pigs were fed grower diets (Table 1) to an average pig weight of 60 kg and then switched to finisher diets (Table 2). Finisher diets were fed until the pigs averaged 102 kg, at which time the feeding phase ended. Diets were formulated on a constant energy (ME):lysine ratio within the grower and finisher diet types. National Research Council (NRC, 1988) requirements were used in diet formu-

lations. Pig weight gain and feed consumption were recorded and feed:grain ratios calculated for the growing-finishing period. Feed and water were continuously available while pigs were on experiment. Pigs were housed in a curtain-sided building in 2.m × 4.5-m pens with solid concrete floors with an open flush gutter across the rear portion of the pen (20% of floor space). The feeding trial was conducted during late spring and early summer.

The HOP used were a mixture of white and split seed. The RP used were 'Florunner' splits. Both types of peanuts were passed through a roller mill (approximately 10 mm space between the rollers) before incorporation into the experimental diets. The CO was crude degummed oil (Cenbra Foods, Lethbridge, AB, Canada) (no antioxidant added). Samples of all three were analyzed for fatty acid profile at a commercial laboratory (Woodson-Tenent Laboratories, Memphis, TN). Samples of the peanuts were also analyzed for total fat/oil content, and these levels were used in the diet formulations. The CO was also analyzed for content of moisture, insolubles, and unsaponifiables. In addition, samples of the diets were obtained and analyzed for moisture, crude protein, either extract, crude fiber, and ash contents also at a commercial laboratory (Woodson-Tenent Laboratories, Memphis, TN).

After the feeding phase was terminated, all pigs were trucked to the University of Florida meats laboratory in Gainesville and slaughtered for carcass evaluations. After chilling for 24 h at 0 ± 2°C, each carcass was scored subjectively for fat firmness (1 to 4 scale with 1 = firm and 4 = soft, oily). Other carcass data obtained included fat depth over the 10th rib, longissimus muscle area (10th rib), lean color (1 to 5 scale with 2 = pale and 3 = pink), marbling score (1 to 10 scale with 1 = devoid and 10 = abundant), and lean firmness (1 to 5 scale with 2 = firm and 3 = slightly firm) of the longissimus muscle evaluated at the exposed surface between the 10th and 11th rib interface. All samples were removed at 24 h postmortem.

For fatty acid analysis, the subcutaneous fat (all layers) was removed opposite the substanteous fat (all area, vacuum-packaged, and frozen (-20°C) for 30 d. Sample preparation and fatty acid composition analysis procedures were similar to those described by Myer et al (1985). Fatty acids were expressed as a percentage of the total sample.

Three boneless center loin chops were removed from one side of each carcass. One chop was used for Warner-Bratzler shear force and two chops were used for sensory evaluation. All three chops were vacuum-packaged in oxygen-impermeable bags (Cryovac B 620 (Cryovac Division. W. R. Grace, Duncan, SC), OTR = 30 to 50 mL/23°C/m2/ 24 h at 1 atmosphere) and frozen at -15°C for

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Loin chops (2.54 cm) for sensory evaluati also cooked on Farberware Open-Hearth. Chops were turned when an internal temp of 50°C was reached and removed from the at a 74°C internal temperature. A trained 1978) nine-member panel evaluated sample 1-cm² cubed using 8- or 6-point descriptive for juiciness (8 = extremely juicy, 1 = ex dry), flavor intensity (8 = extremely inten extremely bland), overall tenderness (8 tremely tender, 1 = extremely tough), a flavor (8 = more detected; 1 = extreme off

The belly was removed from one side animal and pumped to 12% of green weight solution of 2.0% NaCl, .75% sucrose, .55% erythorbate, .3% sodium tripolyphospha .0156% sodium nitrate. Bellies were allo cure for 4 h and then thermoprocessed

approximately 45 d until analyses could be conducted. A Warner-Bratzler shear device (G. R. Electric, Manhattan, KS) was used to obtain peak shear force values of longissimus from cooked loin chops. Chops were thawed 18 h in a cooler (2 ± 3°C), then broiled on Farberware Open-Hearth Broilers (Walker Kidde, Bronx, NY) to an internal temperature of 74°C (AMSA, 1978). Internal temperatures of chops were monitored using copper-constantan thermocouples attached to a Leeds and Northrup Speedomax potentiometer (North Wales, PA). After samples were cooled to 21°C as many cores (1.27 cm diameter) as possible were removed parallel to fiber orientation and sheared perpendicular to the muscle fibers on a Warner-Bratzler shearing device. Cooking losses were determined by weight differences between thawed and cooked chops.

Table 1. Composition of grower diets [33 to 60 kg]

Ingredient	Control (1)	Peanut[a] (2, 3)	Canola oil (4)
	%	%	%
Ground corn	77.00	59.25	52.00
Soybean meal (48% CP)	20.00	18.00	24.00
Dicalcium phosphate	1.30	1.30	1.30
Calcium carbonate	1.00	1.00	1.00
Salt	.20	.30	.30
Vitamin premix[b]	.20	.20	.20
Trace mineral premix[c]	.05	.05	.05
Antibiotic premix[d]	.15	.15	.15
Rolled peanuts[e]	0	21.75	0
Canola oil[f]	0	0	10.0
	100.00	100.00	100.00
Calculated composition[g]			
Lysine	.91	.91	.90
Calcium	.73	.73	.74
Phosphorus	.59	.60	.57
ME, kcal/kg	3,315	3,630	3,700
ME/Lys, kcal/% lys	4,065	3,990	4,110
Analyzed composition[h]			
Moisture	13.3	11.5 11.2	11.2
Ether extract	2.5	12.5 12.1	12.6
Crude protein	18.0	20.0 12.1	18.1
Crude fiber	2.3	3.9 3.4	3.0
Ash	4.5	4.5 4.7	4.4

[a]Diet 2, high-oleic-acid experimental breeding line of peanuts (whole and splits, 43.9% ether extract and 5.3% moisture); and diet 3, 'Florunner' peanut (splits; 44.5% either extract and 8.0% moisture).

[b]Provided the following per kilogram of diet: vitamin A, 4,400 IU; vitamin D₃, 700 IU; vitamin E, 18 IU; vitamin K activity, 2.8 mg; riboflavin, 3.5 mg d-pantothenic acid, 14 mg; niacin, 18 mg; choline chloride, 440 mg; and vitamin B₁₂, 18 µg.

[c]Provided the following per kilogram of diet: Zn, 109 mg; Fe, 50 mg; Mn, 27 mg; Cu, 5 mg; I, 0.9 mg; and Se, .1 mg.

[d]Provided 33 mg of tylosin per kilogram of diet.

[e]Lightly rolled.

[f]Degummed crude canola oil (MIU of 20, .15, and 1.2).

[g]Calculated using NRC (1988) table values with peanuts containing the following: 4,300 kcal/kg of ME, .83% lysine, .10% Ca, and .60% P, and with ME of canola oil = 7,300 kcal/kg.

[h]Diets 2 and 3, average of duplicate samples.

[i]Diets 2 and 3, respectively.

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internal temperature of 60°C. After cooked bellies had cooled to 2°C they were sliced and sample slices were removed at random and placed in a vacuum bag (Cryovac B 820 [Cryovac Division, W. R. Grace], QTR = 30 to 50 ml/23°C/m²/24 h at 1 atmosphere and frozen at –15°C for approximately 45 d until sensory analysis could be conducted. Bacon samples for sensory evaluation were thawed in a cooler (2°C ± 3°C), cooked, then served while warm to a trained (AMSA, 1978) nine-member sensory panel. Samples for sensory evaluation were placed on absorbent paper plates lined with paper towels and cooked by microwave heating on high power for approximately 1 min per slice. Samples were cut into 2-cm pieces and presented to panelists in warm glass jars. Panelists were given three pieces per sample

(animal) to evaluate. Training was accomplished with the use of salt solutions (of different concentrations) and commercial bacon (purchased at local stores) with different flavor and salt intensities. Each sample was evaluated using 8- or 5-point descriptive scales for saltiness (8 = none, 1 = extremely salty), flavor intensity (8 = extremely intense; 1 = extremely bland), crispness (6 = very crisp, brittle; 1 = very soft), oiliness/mouth feel (6 = none, 1 = extreme, heavy waxy). Off-flavors were noted for each sample but were not quantified.

Data were analyzed by the analysis of variance procedure (SAS, 1985); the experimental unit was the individual animal except for growth and feed efficiency data, for which the pen was the experimental unit. The Waller-Duncan k-ratio test

Table 2. Composition of finisher diets (60 to 102 kg)

Ingredient	Control (1)	Peanuts (2, 3)	Canola oil (4)
	%		
Ground corn	83.40	83.15	89.80
Soybean meal (48% CP)	14.00	12.50	17.50
Dicalcium phosphate	1.15	1.15	1.15
Calcium carbonate	.90	.90	.90
Salt	.30	.30	.30
Vitamin premix[a]	.15	.15	.15
Trace mineral premix[c]	.05	.05	.05
Antibiotic premix[d]	.05	.05	.05
Rolled peanuts[e]	0	21.75	0
Canola oil[f]	0	0	10.00
	100.00	100.00	100.00
Calculated compositions[g]			
Lysine	.44	.72	.72
Calcium	.65	.66	.66
Phosphorus	.54	.54	.52
ME, kcal/kg	3,330	3,830	3,710
ME/lys, kcal/% lys	5,200	5,070	5,190
Analyzed composition[h]			
Moisture	12.7	11.2, 11.3	10.8
Ether extract	3.1	12.6, 12.1	12.0
Crude protein	13.5	17.2, 17.2	13.7
Crude fiber	2.5	2.7, 3.0	2.0
Ash	3.5	3.6, 3.9	3.6

[a]Diet 2, high-oleic acid experimental breeding line of peanuts (whole and splits; 45.9% ether extract and 5.3% moisture), and diet 3, 'Florunner' peanuts (splits; 45.5% ether extract and 8.0% moisture).

[b]Provided the following per kilogram of diet: vitamin A, 3,300 IU; vitamin D₃, 825 IU; vitamin E, 14 IU; vitamin K activity, 2.0 mg; riboflavin, 2.8 mg; d-pantothenic acid, 10 mg; niacin, 14 mg; vitamin B₁₂ chloride, 330 mg; and vitamin B₁₂, 14 µg.

[c]Provided the following per kilogram of diet: Zn, 100 mg; Fe, 50 mg; Mn, 27 mg; Cu, 5 mg; I, 3 mg; and Se, .1 mg.

[d]Provided 27.5 mg of zinc bacitracin per kilogram of diet.

[e]Lightly rolled.

[f]Degummed crude canola oil (MIU of 20, .15, and .12).

[g]Calculated using NRC (1988) table values with peanuts containing the following: 4,800 kcal/kg ME, 32% lysine, .10% Ca and .40% P; and with ME of canola oil = 7,300 kcal/kg.

[h]Average of duplicate samples. Diets 2 and 3, respectively.

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Table 3. Fatty acid composition of high-oleic-acid peanuts (HOP), regular peanuts (RP), and canola oil (CO)

Item	HOP	RP[a]	CO[b]
		%	
C16:0	7	10	4
C18:0	3	3	2
C18:1	78	53	60
C18:2	4	27	20
C18:3	0	1	11
C18:0	1	1	0
C20:0	2	0	2
C20:1	2	1	2
C22:0	4	3	1
C22:1	0	0	1
C24:1	2	2	1
Total saturated[c]	18	15	6
Total monounsaturated[d]	77	54	62
Total polyunsaturated[e]	4	27	31

[a]Flavorrun' splits.
[b]Crude degummed oil.
[c]Total of C16:0, C18:0, C20:0, C22:0, and C24:0.
[d]Total of C16:1, C18:1, C20:1, and C22:1.
[e]Total of C18:2 and C18:3.

Results and Discussion

was used to compare treatment means when significant (P < .05) treatment effects were observed.

In comparison to RP, HOP were higher in monounsaturated fatty acids, primarily the C18:1 fatty acid, and lower in polyunsaturated fatty acids, primarily C18:2 (Table 3). The levels of the other fatty acids were very similar between the two types of peanuts. Canola oil was quite high in monounsaturated fatty acids, but not as high as HOP. Unlike HOP, CO also contained an appreciable amount of polyunsaturated fatty acids, in

particular the C18:3 fatty acid. In comparison, other high-oleic vegetable oils such as high-sunflower and safflower oils, HOP was similar in total monounsaturated fatty acids and was in total polyunsaturated fatty acids (4% vs 15%; Miller et al., 1990; Rhee et al., 199...

Pigs readily consumed the peanut and CO diets were slightly greater than those of control pigs, and ADG of the pigs fed CO significant (P < .05) (.93 for control vs .85, .94 ... 1.00 kg/d for HOP, RP, and CO treatm... respectively). Feed:gain ratios from pigs fed ... of the peanut treatments or the CO treat... were similar and averaged 12% better (P < ... than the control pigs.

Dietary treatment was found to have no ... on longissimus muscle area, lean color or ... ness, or amount of marbling (Table 4). Ba... thickness, however, tended to be greater (P <... for pigs from any of the fat/oil treatments the ... pigs fed the control diet. The slight increa... backfat was consistent with that usually obs... upon the addition of fat/oil to swine diets (St... 1984). However, we and others have noted no ... on backfat thickness upon feeding CO or ... oleic-acid sunflower or safflower oils (St. Jo... al., 1987; Miller et al., 1990; Myer et al.,... Miller et al. (1990), however, did note a nons... cant trend for increased backfat thickness for ... fed the fat/oil-containing diets.

The lack of an effect of additional fat/... marbling and lean color was in contrast t... decrease in marbling and color scores that w... others have observed from feeding diets hi... unsaturated fat (St. John et al., 1987; Wes... Myer, 1987; Miller et al., 1990; Myer et al., 19... our previous studies, however, subsequent a... sis indicated that the fat content of the loin... not affected. This indicated that the marblin... present but may not have been readily v...

Table 4. Carcass characteristics of growing-finishing swine fed diets containing high-oleic-acid peanuts (HOP), regular peanuts (RP), or canola oil (CO)[a]

Item	Dietary treatment				
	Control	HOP	RP	CO	SE
Avg backfat,[b] cm	3.5[a]	3.7[b]	3.7[b]	3.8[b]	.1
Longissimus muscle area,[b,f] cm²	29	26	28	27	1.0
Lean color score[c]	2.9	2.4	2.3	2.7	.2
Marbling score[d]	4.0	3.9	3.4	3.8	.4
Lean firmness score[e]	2.4	2.1	2.2	2.2	.2

[a]Each mean is based on information from 12 animals.
[b]Adjusted to 100 kg live weight.
[c]Scores: 1 to 5; 2 = grey; 3 = light pink.
[d]Scores: 1 to 10; 3 = traces; 4 = slight; 5 = small.
[e]Scores: 1 to 5; 2 = firm; 3 = slightly firm.
[f]Means do not differ (P > .10).

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Table 5. Fatty acid analysis and fat firmness of carcass fat from growing-finishing swine fed diets containing high-oleic-acid peanuts (HOP), regular peanuts (RP), or canola oil (CO)[a]

Item	Dietary treatment				
	Control	HOP	RP	CO	SE
Fatty acids[b], %					
C14:0	2[i]	2[i]	2[i]	1[b]	.1
C16:0	27[i]	30[k]	30[k]	27[k]	.2
C18:0	9[i]	9[i]	9[i]	9[i]	.2
C18:1	12[i]	2[k]	2[k]	2[k]	.2
C18:2	35[h]	43[j]	43[j]	7[k]	.2
C18:1	1[i]	2[i]	30[k]	10[k]	.2
C18:2	4[j]	17[k]	17[k]	10[k]	.3
C18:3	1[b]	2[i]	2[i]	9[k]	.2
Total monounsaturated[c], %	41[h]	54[k]	4[k]	4[k]	.2
Total polyunsaturated[d], %	10[i]	9[k]	19[k]	17[k]	.3
Total saturates[e], %	49[i]	37[j]	37[j]	35[k]	.2
Unsaturate ratio[f]	1.1[i]	1.7[i]	1.7[j]	1.9[i]	.1
Avg fat firmness score[g]	1.6[j]	1.9[m]	2.9[m]	2.1[m]	.2

[a]Each treatment mean is based on information from 12 animals.
[b]Fatty acid analyses were done on backfat samples. Fatty acids are reported as a percentage of total fatty acids.
[c]Total of 16:1, 18:1, 20:1, and 22:1.
[d]Total of 18:2 and 18:3.
[e]Total of 14:0, 16:0, and 18:0.
[f]Ratio of total unsaturates (mono and poly) to total saturates.
[g]Scores: 1 to 4; 1 = firm, 2 = slightly soft, 3 = soft, 4 = very soft, oily.
[h,i,j,k]Means in the same row with a different superscript differ (P < .01).
[l,m]Means in the same row with a different superscript differ (P < .05).

West and Myer, 1987; Myer et al., 1992). The previously observed decreases in lean color scores were mostly of a small magnitude (St. John et al., 1987; West and Myer, 1987; Miller et al., 1990; Myer et al., 1992).

Carcasses from pigs fed the RP or CO diets had fat that was softer (P < .05) than that obtained from carcasses of the control pigs (Table 5). This finding is in agreement with other studies in which pigs were fed peanuts or CO (St. John et al., 1987; West and Myer, 1987; Miller et al., 1990; Myer et al., 1992). The average fat firmness score of carcasses from pigs fed HOP was not significantly different (P > .05) from that of carcasses from the control pigs.

Compared with the control, each of the three dietary fat/oil sources resulted in an increase (P < .01) in total monounsaturated fatty acids in the carcass fat; HOP resulted in the greatest increase (P; increase; Table 5). In regard to total polyunsaturated fatty acids, both the RP and CO fat/oil sources resulted in an increase (P < .01), whereas the HOP fat/oil source resulted in an actual decrease (P < .05) compared with the control pigs. Total saturated fatty acids decreased (P < .01) upon feeding any of the three fat/oil sources; CO resulted in the greatest decrease. Changes in the fatty acid profile noted above were reflective of the fatty acid profile of the three dietary oil sources.

total unsaturated fatty acids noted upon feeding HOP agree with results of trials involving other high-oleic acid vegetable oils (Rhee et al., 1988a; Miller et al., 1990). Total polyunsaturated fatty acids in these other trials, however, stayed the same or were actually increased, unlike the actual decrease we observed. This difference between trials was due to the residual level of polyunsaturated fatty acids in the high-oleic sunflower and safflower oils and the very low level of polyunsaturated fatty acids in HOP. The low level of polyunsaturated fatty acids in HOP also explains the lack of a significant effect on carcass fat firmness. Miller et al. (1990) still noted significant decreases in carcass fat firmness due to feeding diets containing 10% high-oleic-acid sunflower or safflower oils.

Total saturated fatty acid percentage of the carcass fat from the control pigs was greater than that we have previously reported with pigs fed similar diet types (50% saturated vs 40 to 42%; West and Myer, 1987; Myer et al., 1992). This may have been due to environmental temperature during the finishing phase of our present and previous trials. Lefaucheur et al. (1991) reported that swine reared in a warm environment had a greater proportion of saturated fatty acids in the carcass fat than pigs reared in a cool environment.

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Table 6. Sensory and shear force values of broiled loin chops from swine fed diets containing high-oleic-acid peanuts (HOP), regular peanuts (RP), or canola oil (CO)[a]

Item	Dietary treatment				
	Control	HOP	RP	CO	SE
Shear force[b,c], kg/1.27 cm²	5.9	5.9	6.5	6.5	4
Flavor intensity, avg score[c]	4.8	5.0	5.0	4.8	1
Juiciness, avg score[c]	3.7	3.8	3.8	3.8	1
Tenderness, avg score[c]	5.1	5.3	5.3	5.3	2
Offflavors, avg score[c]	5.8	5.9	5.7	5.8	1
Cooking loss, %	32	33	33	32	8

[a]Each mean is based on information from 12 animals.
[b]Warner-Bratzler shear force values.
[c]Scores: 1 to 8 scale with the trait increasing with an increase in score.
[d]Scores: 1 to 8 scale with a less intense off-flavor with an increase in value.
[e]Means do not differ (P > .10).

previous trials, the finishing periods were during cooler periods of the year. Nevertheless, percentages of the various fatty acids of the control treatment in our present trial were within the range of values reported by Barschauer (1966).

In general, dietary treatment was found not to influence (P > .05) sensory traits of broiled loin chops (Table 6). Flavor, crispiness, oiliness, and saltiness of cured bacon also were found not to be affected to any degree, but the incidence of off-flavors was affected (Table 7). Bacon from pigs fed CO had a higher incidence (P < .05) of off-flavors than was noted with bacon from pigs fed the other treatments. Most of the off-flavors were described as being rancid in nature. No off-flavors were detected in bacon samples from pigs fed HOP.

The lack of effect of treatment on palatability evaluations of broiled loin chops agrees with the results that we and others have previously ob-

served upon feeding diets containing peanuts, or high-oleic-acid sunflower or safflower oils John et al., 1987; West and Myer, 1987; Miller al., 1980; Rhee and Ziprin, 1980). However, Miller al. (1990) reported that chops from pigs fed diets had a high incidence of detectable off-flavor The high incidence of off-flavors that we no with bacon from pigs receiving the CO treatm agrees with the finding of Shackelford et (1980a). The off-flavors are thought to be linked a high level of linolenic acid (C18:3) in CO (Rhee al., 1988a; Miller et al., 1990; Shackelford et 1990a). The lack of an effect of feeding HOP di on subsequent palatability and acceptability bacon also agrees with the findings of Shackelf et al (1990a) in trials using high-oleic-acid s flower and safflower oils. However, Shackelford al. (1990a) noted a decrease in bacon crispin from the high-oleic sunflower and safflower treatments that we did not observe upon feed

Table 7. Sensory values of fried cured bacon strips from swine fed diets containing high-oleic-acid peanuts (HOP), regular peanuts (RP), or canola oil (CO)[a]

Item	Dietary treatment				
	Control	HOP	RP	CO	SE
Flavor intensity, avg score[b]	5.6[e]	5.5[f]	5.5[e]	5.6[ef]	1
Saltiness, avg score[b]	5.1	4.4	5.2	4.5	2
Crispiness, avg score[b]	4.1	3.8	3.7	4.2	2
Oiliness, avg score[b]	3.6	3.8	3.7	4.0	2
Incidence of offflavors, %[c,d]	0[e]	0[e]	4[e]	92[f]	1

[a]Each mean is based on information from 12 animals.
[b]Scores: 1 to 8 scale with the trait increasing with an increase in score for saltiness, and decreasing with an increase in score for flavor intensity, and decreasing with an increase in score for crispiness, and decreasing with an increase in score for oiliness.
[c]Scores: 1 to 8 with the trait increasing with an increase in score for crispiness, and decreasing
[d]Percentage of samples with any off-flavors.
[e,f]Means in the same row with a different superscript differ (P < .05)

HOP. The reason(s) for this disagreement is(are) not known but may be related to the method of bacon preparation (pan frying vs microwaving) or to the level of residual polyunsaturated fatty acids in the oils (8 to 15% vs 4%).

The feeding of oil from HOP resulted in an increased level of total unsaturated fatty acids in the carcass fat without an increase in the level of polyunsaturated fatty acids, and with only a minimal effect on increasing the "softness" of the carcass fat. The inclusion of this oil source in the diet also resulted in no detectable effects on various carcass and meat quality characteristics.

Implications

The inclusion of vegetable oils high in monounsaturated fatty acids and low in polyunsaturated fatty acids, such as the oil in high-oleic-acid peanuts, may offer a means to increase the level of unsaturated fatty acids in pork fat with little or no undesirable side effects on carcass and meat quality characteristics.

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Dietary Influencers of Pork Quality and Practical Solutions to Quality Problems

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Executive Summary

While many dietary factors can be found in the research to exert influence over pork carcass quality, only one is of significant pratical consequence, dietary fat. Fat is an economically important ingredient to swine producers, particularly in the Southeast where corn price is high due to the cost of transport from the Midwest and fat prices are low because of high supplies of restaurant grease. In the Southeast, the fat:corn price ratio has historically fallen been between 2:1 and 3:1, a range which will consistently result in substantial feed cost savings. Also, because energy cost accounts for about 80% of the cost of feeding swine, and fat is an energy source, the question of whether or not to feed fat is one of the most important economic questions when formulating swine diets.

History and research clearly demonstrate that the type and quantity of fat fed to swine can influence the composition of fat observed on the carcass. The Industry has selected hogs for greater leanness, and we have now completed the transition nationwide to reflect these genetic changes. Accordingly, the problem of soft-fat has increased because of less total fat on the animal and because the type of fats available for feeding have shifted from saturated animal fat to unsaturated vegetable oils. It is this combination that has led up to the current situation and the predominant reason for the differences in fat quality between production regions in the U.S.

Iodine value (IV) is an Indicator of the degree of fat saturation or hardness and in swine this figure will generally run between 60 and 100. A lower IV indicates harder fat (e.g., 45, tallow), and a higher number softer (130, soybean oil). Interestingly, if we feed a dlet low in fat, the animal will manufacture and store a fat that contains very high quantities of highly saturated (hard) fat and is indicative of historical feeding trends for Midwestern farmers. However, as the fat content of the diet increases, the animal will take those fats from the diet and store them in their fat reserves, thus resembling more closely the type of fat being fed. Therefore, carcass IV is modified both by changes in the type of fat fed and the quantity of fat fed.

Because carcass IV is related to both the IV of the fat fed and the quantity of the fat fed, researchers created a mathematical equation that attempts to predict carcass IV based dietary measures. Iodine value product (IVP) is a calculation based diet composition that reflects the total amount of IV fed to the animal. This measure is incorporated into the formulation method, allowing targets to be set and economic evaluations conducted to assess the cost of modifying carcass IV.

It is important to also recognize that the cost of changing carcass IV targets is considerable, and the amount of variance from group to group large. The standard deviation in the carcass results can range from 3.5 to 4.5, suggesting that one must carefully weigh decisions to make adjustments in carcass IV because the results can be misleading due to normal variance. In order to detect a 1 point change in IV, one must measure 320 carcasses, or 80 carcasses must be measured to detect a 2 point shift using standard statistical power tests. Therefore, one must be careful not to over-interpret system results where changes have been made, without giving due consideration to the normal variance among and within groups.

Murphy-Brown LLC has used IVP formulation to modify carcass IV. Results indicate that the PIC equation is not accurate for the Murphy/Smithfield system for absolute carcass IV prediction. However, results indicate that the equation will reasonably predict relative changes in carcass IV due to diet IVP changes. Also, the data demonstrate that by feeding diets with lower fat and consequently lower IVP, carcass IV will be reduced (such as wheat feeding, tallow feeding, or reduced fat diets). It is recommended that producers use the IVP formulation method, but refine the prediction equations to fit their own production and processing systems.

An Introduction to Soft Fat

Issues of soft-fat in pork carcasses are a growing problem. These problems tend to occur to a larger extent in the Southeastern U.S., as compared to the Midwestern U.S., even within similar genotypes of hogs. There are many reasons for these differences and this paper will attempt to highlight why the problem is observed and how one can overcome the problem.

Soft-fat is typically highlighted as soft-bacon, and often results in poor slicing yields and packaging problems. Additionally, consumers will observe problems with separation and cohesiveness of the product. The problem is significant enough to warrant development of measurement systems to help quantify the problem, such as stick test, penitrometer, and IV test, to name a few. While the issue is most apparent to the consumer in bacon, the breadth of impact for the food processor extends to all fresh meat products, as well as trim.

As one goes through a processing facility that has masses of product passing through, it is not difficult to identify where problems will arise. Loins for example, will have fat layer separation, creating non-uniform fat coverage problems. Non-uniform coverage in such cases will result in product not meeting specification, increasing product failure rate and costs. Similarly, some have suggested that soft fat is potentially responsible for muscle separation in the ham and shoulder, resulting in consumer acceptance problems. Trim from carcasses of animals having soft-fat cannot be used successfully in sausage patty formation, the patties stick to the machinery and fail to hold their shape. All of these problems lead up to increased manufacturing costs and lost markets for the food producer and the entire food chain.

Technically, soft fat is a reflection of the change in fatty acid composition away from saturated fat, toward higher levels of unsaturated fat. It is ironic that the medical and public health community have been promoting a greater shift toward the consumption of unsaturated fats in order to lower the risk of coronary heart disease (CHD). However, it seems clear that consumers will trade the risk of CHD for a product that meets their quality criteria. Perhaps markets exist for both types of products.

Soft-fat is a problem that affects all pork products. It is a problem that is influenced by many economically important traits, both to the food processor and the livestock producer. However, there is little or no data available to predict the change in carcass value due to changes in carcass IV, making it practically impossible to conduct cost/benefit analyses and determine the value of dietary changes. Development of low-cost, practical, solutions to the soft-fat problem are necessary in order to ensure a future in the pork product marketplace.

Dietary Fat, History and Use

Researchers discovered in the early to early-1900's that pigs, unlike cattle and sheep, are what they eat. While a slight oversimplification of reality, this is a conceptually true statement. To a large extent, what we feed pigs greatly influences the type of fat that is put into the fat storage reserves on the animal. Indeed, the pig has the ability to take fat from the diet and deposit it directly into fat cells, a characteristic rather unique to non-ruminant animals. It is this phenomena which links the diet composition with the carcass composition, and why we must be concerned with what we feed our animals

A discussion on fat must address the reasons why one chooses to feed fat in the first place. While there are known requirements for specific fatty acids (such as linoleic acid), we know that only very low levels of fat are necessary in common ingredients to meet these nutritional requirements. Therefore, the question of why do we feed very high levels of added fat to swine must be asked. The simplest answer lies in a question of economics. First, it is known that animals eat to their energy requirement, which is described generally in terms of the requirement for maintenance and the requirement for some productive function, such as growth, fetal development, or milk production. Additionally, chemistry tells us that fats (and oils) have about 2.25 times more energy than carbohydrates or protein, which means that 1 lb. of fat is equal to 2.2 lb. of carbohydrates or protein. It is also of importance to note that dietary energy content accounts for about 80% of the diet cost. Thus, no nutrient is of greater economic importance than energy in swine diets and it is the first economic decision that must be made in formulation of the diets.

Economic Value of Added Fat

For the US swine producer, the prices of corn, soybean meal and fat are the major influencers of feed costs. Because corn is the primary feed energy substrate in the U.S., the relationship between corn and fat is of utmost importance when formulating diets. Most common ingredients have some combination of carbohydrates, protein and fat, along with significant quantities of water (Table 1). If we focus only on energy, fat has about 2.4 times more energy than corn or wheat. In a mixed ration however, these two ingredients usually only constitute 70 to 80% of diet, with dilution coming from lower energy protein supplements and mineral additions. Combining the dilution factors of moisture, minerals, and differences in nutrient density, we can understand why the simple equation of 2.25× more energy is not quite accurate, and the feeding value typically exceeds a 3:1 ratio when compared within a diet.

As the animal ages both the rate and composition of growth changes, resulting in changes in dietary nutrient requirements. In general, the relative density of non-energy components, amino acids/protein and minerals, are highest in young pig diets and decrease with age. Also, for newborn or newly-weaned pigs, the diet composition is quite complex, containing large quantities of very expensive specialty ingredients. The need for such specialty products also diminishes with age. Thus, as the animal ages, the diet costs decrease and the percentage corn (or similar cereal) in the diet increases. It is for this reason that the value of fat is largely dictated by corn price, and that the relative value of fat diminishes as the animal ages. In short, fat has the most value in the most expensive diets and the least value in the least expensive diets. Other elements that influence whether or not fat is to be fed include dust control/respiratory health, alternative ingredient pricing, etc. For most swine diets however, the relative cost of fat compared to corn is the single largest factor influencing the decision to feed fat and what level of fat to feed.

Historical research data demonstrate that adding fat to swine diets can increase the rate of growth, thus reducing the days to market. As geneticists have selected for leaner animals, the degree of growth response to added fat may have decreased. One can find research data that suggests a growth rate response can be observed in modern genotypes due to added fat, but data to the contrary appear to be equally available. Today, apart for the potential health benefits associated with reducing dust levels through fat inclusion, it is not clear that a producer can expect a lean growth rate increase in high-lean animals due to added dietary fat.

The Evolution of Fat Feeding & The Soft Fat Problem

Historically, fat feeding has not been a cost-effective alternative for swine producers in the Corn Belt. The primary reasons why are fairly simple. Animal fat, which was the available fat for the typical Midwest pork producer, was used for frying foods and in baked goods. These markets traded at significant premiums compared to today's feed fat market, making fat feeding a very unattractive venture when corn prices are low. It was not until the consumer shifted demand from animal fats to vegetable oils that fat became available to most major US pork producers. The other piece of this equation is that hogs were typically fed by producers as a means to market their corn crop. Therefore, even if fat were available, the cost of the corn observed by the producer was so low that fat did not appear attractive. In brief,

Midwestern hog producers have not historically used fat in feed because they had cheap corn and limited access to a fairly expensive fat market, some of which still exists today.

In the Southeast, abundant supplies of low-cost spent restaurant grease have been created due to the high population density. This low-cost fat allowed Southeastern swine and poultry producers to import corn from the Midwest and achieve a fairly competitive feeding cost, competing on a national basis with the Midwestern livestock producer. This combination of high-priced corn and cheap fat led up to the rapid adoption of fat feeding in the Southeast. During the 1980's, restaurateurs responded to shifts in consumer demands, switching from animal fats to vegetable oils or partially hydrogenated vegetable oils for their frying needs. This resulted in a significant shift in the composition of feeding fat in the Southeast, today more closely resembling vegetable oil or unsaturated fat.

The change in consumer attitudes toward fat consumption also caused a major push by the US Pork Producers to create a very lean animal. Genetic progress through the 1980's allowed the pork producer of the 1990's grow and sell a very lean animal, one which obtained significant lean premiums. Continued selection and economic pressure against fat on the carcass has ultimately resulted in complete population shift, where essentially all animals are genetically lean and contain a very limited quantity of fat on the carcass. This genetic change has also resulted in a shift in the amount of fat available at the packing plant and the composition of the fat in the animal. It is this combination of lean animals, the availability of highly unsaturated fats, and the lack of availability of saturated fat that has resulted in a soft-fat product somewhat unique to the Southeastern U.S.

Soft-Fat Solutions

The history presented above is only of academic importance. Finding solutions to the problems created is the immediate need. It is clear that high-lean animals can have relatively hard fat in their carcasses, the question becomes "What is the most economical means to achieve a desirable carcass". One answer certainly might include genetic selection of animals for either greater fatness or lower carcass IV's, neither of which can provide solutions in the near-term. Practically, for the short-term, dietary manipulation of carcass IV is the only solution, whether it be in the form diet fat type or fat level.

Fat type within the context of this paper, refers specifically to the chemical composition of the fat. Tallow, for example, is a type of fat that is highly saturated and when fed will cause a shift in the degree hardness of the pigs carcass. Similarly, soybean oil is a highly unsaturated fat that will have essentially the exact opposite effect as tallow. Categorically, low-IV fats are those fats containing saturated fat, while high-IV fats are those containing predominantly unsaturated fats. Given a choice, one would certainly prefer to feed a categorically low-IV fat to overcome soft-fat.

We also know that animals fed low-fat diets will have lower IV carcasses than animals fed high-fat diets. The basic biology of this phenomena is quite understandable. Indeed, the pig will take fat from the diet to fill its fat cells, but, in the absence of dietary fat the pig will also manufacture its own fat in order to fill these cells. The fat of dietary origin will compositionally resemble the fat fed, while the fat manufactured by the animal will uniquely be high in saturated fat.

Iodine Value Product Formulation

Using the aforementioned knowledge, researchers have been able to create mathematical equations to predict carcass IV. Pig Improvement Company (PIC; Tech Memo 153) reported that carcass IV can be predicted by using the product of the level of fat and the IV of the fat fed, termed iodine value product (IVP). Ingredient IVP is calculated as follows: IVP = IV of fat × % fat ÷ 10. For example, the IV of corn oil is 128 and corn contains 3.5% fat, therefore the IVP of corn is $125 \times 3.5 \div 10$, or 44.8. Diet IVP can then be calculated by taking the ingredient IVP's times there percentage in the diet, and summing the result. Subsequently, the following prediction equation was developed by the researchers to estimate carcass IV: Carcass IV = .315 × diet IVP + 52.4.

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The result of incorporating IVP into the formulation method is the ability to assess the cost of feeding to a specific carcass IV. It is the ability to set dietary targets with predictable outcomes that allows us to predict feed cost impacts. While the accuracy of the prediction equations may be somewhat variable and may need to be adjusted to fit a specific system, the methodology allows cost impact assessment. The companies of Murphy-Brown LLC implemented IVP formulation in June 2000 and continue to utilize this technology today as an integral part of the formulation method.

Murphy-Brown Results 2000 to Present

Results can be broken into several categories. First, one must ask are we able to adequately predict the impact of dietary changes on the resulting carcass IV. Secondly, do the results respond in a manner consistent with the predicted response and is the predictability maintained over time. Predictability of the results is necessary in order to effectively administer and manage program costs and results.

Validating the Predictability of Carcass IV

Results obtained from the Murphy system are of particular interest because this system has had the same approach over the past 18 months. Also, Murphy has 2 different genetics that are fed diets differing only in IVP (5 points) for the last diet fed before market. Additionally, the results from this system demonstrate the results of several key changes, as well as highlight several major deficiencies in the predictability of the results.

Between September and December 2000, the Murphy non-select genetic IV data (Figure 1) indicate that the actual results were not coinciding with the predicted results (see Table 2). In fact, it appeared that the actual results tended to run 2 to 3 points higher than predicted, suggesting the prediction equation may not be accurate for the Murphy/Smithfield system. This lack of predictability was concerning, but based on historical data it was believed that carcass IV had dropped by 2 to 3 points.

Additional changes were made in the Murphy Finisher 1 and Developer in November 2000, with the expectation that imposing greater restriction on diet IVP during late finishing would in fact have a greater impact on carcass IV. The results of this change are not evident in the run chart (Figure 1), suggesting that carcass IV is related to the entire lifetime feeding of the animal. Contrary to the change implemented in November, the data demonstrate a significant increase in mean IV value beginning in December 2000, with an additional increase in February 2001. Both of which carried through until April 2001. It is not clear why the results responded in this manner, although it is noteworthy that system backfat levels attained their lowest point in history during the February to April 2001 time-frame. It is not clear that the IV change is related to the backfat change at that point in time, but this proposition should not be ruled out.

Based on the data between September 2000 and April 2001, it is clear that the actual carcass IV's obtained are substantially higher than the predicted values, by as much as 3.5 to 4 points. This suggests that the baseline may be different among systems, which is consistent with other data available. Based on research conducted at Clemson (McConnell and Maurice, unpublished data), one can demonstrate the impact of diet IVP on carcass IV results (Figure 2). While not calculated by the researchers, the data can be used to obtain a prediction equation between diet IVP and carcass IV. The Clemson data demonstrate a similar change in carcass IV per unit change in diet IVP to those of PIC (Figure 3), .296 for Clemson vs. .315 for PIC. However, the intercepts are substantially different when using the same IV calculation, 41.8 for Clemson and 52.4 for PIC. This suggests that a change in diet IVP will cause a similar change in carcass IV using either equation, but the absolute value will be different. It is therefore believed that PIC slope is reasonably accurate, but the intercept within the Murphy/Smithfield system should be about 55.9.

Validating the Directional Response to Changes in Diet IVP

Another system change occurred in the May/June 2001 time-frame, which is most evident in Murphy select genetics (Figure 4), and resulted in a significant reduction diet carcass IV. Specifically, the incorporation

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of wheat into finishing formulas is believe to be responsible for the change in both genetics, but most evident in the select genetics because it was specifically targeted in these pigs diets. Conversely, the data also clearly demonstrate when wheat left the diets around the 1ˢᵗ of August due to short supplies. Diets containing wheat can run as much as 9 points lower in diet IVP, predictably resulting in a 3 point reduction in carcass IV. Both genetics tended to run around 3 points lower than the Springtime values, suggesting the degree of response is similar to the predicted response.

One of the most interesting points in all of these data is a single point in the non-select genetics having an IV of around 68.5, an outlier. This point represents a set of gilts fed a diet throughout finishing which had no more than 2.25% added fat (yellow grease). This low-fat diet has an IVP of 51, compared to the average IVP of 75 for the standard program. Based on the PIC value of .315, we would expect this group to have an IV 7.4 points lower than commercial groups, perhaps in the range of 71 to 72. Again the absolute change is not entirely correct, but it is clear that the results were in fact directionally correct. This one group helps bring validation to at least one core principle of IVP formulation, the animal will have a low carcass IV if fed diets low in added fat.

Since the middle of August, it appears that there has been a dramatic shift in the amount of variance experienced from group to group, along with a rise in carcass IV's over the Spring and prior Fall. The only program change that occurred around this time frame was the elimination of the finisher 2 diet. However, it is not clear that this change was of significance because not all groups would have received this feed. Actually, the finisher 2 feed would have only been fed in the last 2 weeks prior to slaughter in those groups that would have actually received it, not all do. The fact that the remaining diet targets remained the same, there is no clear answer as to why current IV levels are above previous results.

Overall, the data demonstrate that the PIC equation can be used with some degree of confidence to predict the degree of change in carcass IV due to changes in diet IVP. Given the fact that the within group and among group variance in carcass IV is between 3.5 and 4, one might not expect to validate this response to a greater degree using system data. Indeed, the recent shift in variance is concerning because such an increase in variance reduces the ability to detect small changes in carcass IV. Because the economic outcome of a 1 or 2 point shift in carcass IV is very significant, understanding the implications of such a change in variance is of equal importance.

The data examined provide some degree of confidence that carcass IV can be predicted from diet IVP. This is particularly true for relative changes. The data also suggest that one will most likely need to establish a baseline or intercept for their own system. The combination of utilizing the slope presented by PIC and establishment of an appropriate baseline will allow the producer to examine the cost implications of making dietary changes that will affect carcass IV.

Summary and Conclusion

Murphy-Brown LLC is committed to improving its pork product quality. With a clear objective of having fewer than 10-15% of our groups exceed the current Smithfield 78 IV maximum, Murphy-Brown has set the weighted average diet IVP maximum of 63. This restriction should yield a carcass having an average carcass IV of 75.6 (adjusted value, see Table 3). Additionally, in order to achieve this target Murphy-Brown has set its Finisher 1 IVP maximum at 49.

It is apparent that one must adjust the intercept used in the PIC equation in order to fit within the Smithfield measurement system, but with this equation it is believed that a producer can reasonably predict the average outcome of dietary changes. The amount of variance in IV level among carcasses is significant, and this cannot be ignored when interpreting the result of minor dietary changes or setting dietary targets. Murphy-Brown has chosen to not exceed the target, and will work toward lower cost solutions once the results have demonstrated success. It is recommended that all producers utilize the IVP formulation method in order to manage carcass IV targets and feed costs, and each producer is encouraged to validate the response of their animals to diet IVP changes.

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Figure 1. Murphy Non-Select Genetic Run Chart.

Murphy Non-Select Carcass IV Data
Individuals

Set 5: UCL=92.743596, Mean=80.353041, LCL=67.992486 (8/14/2001-10/15/2001) (mR=2)

Moving Range (2)

Set 5: UCL=15.225117, Mean=4.658649, LCL=none (8/14/2001-10/15/2001) (mR=2)

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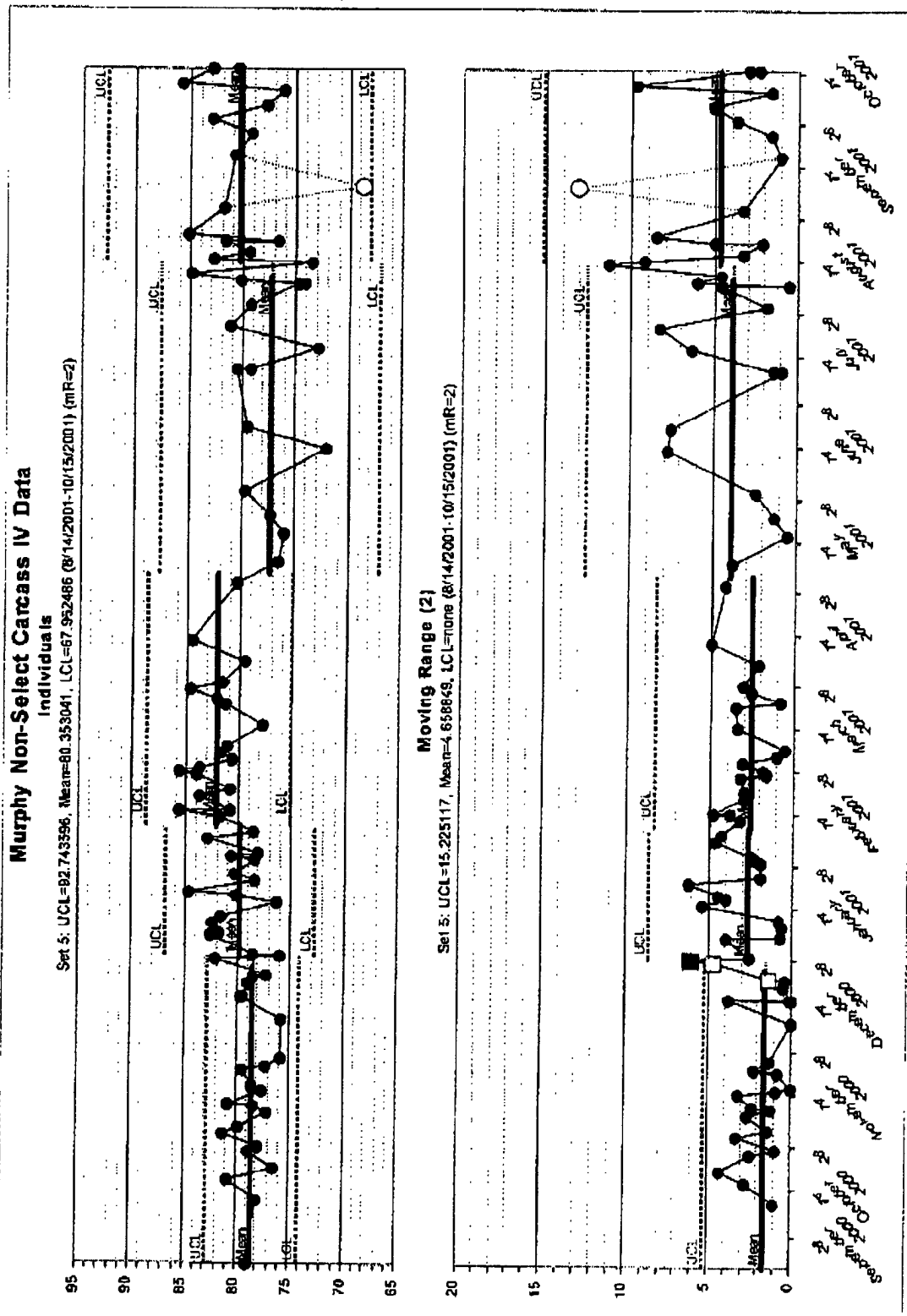
Figure 2. Impact of Feed Fat on Carcass IV.
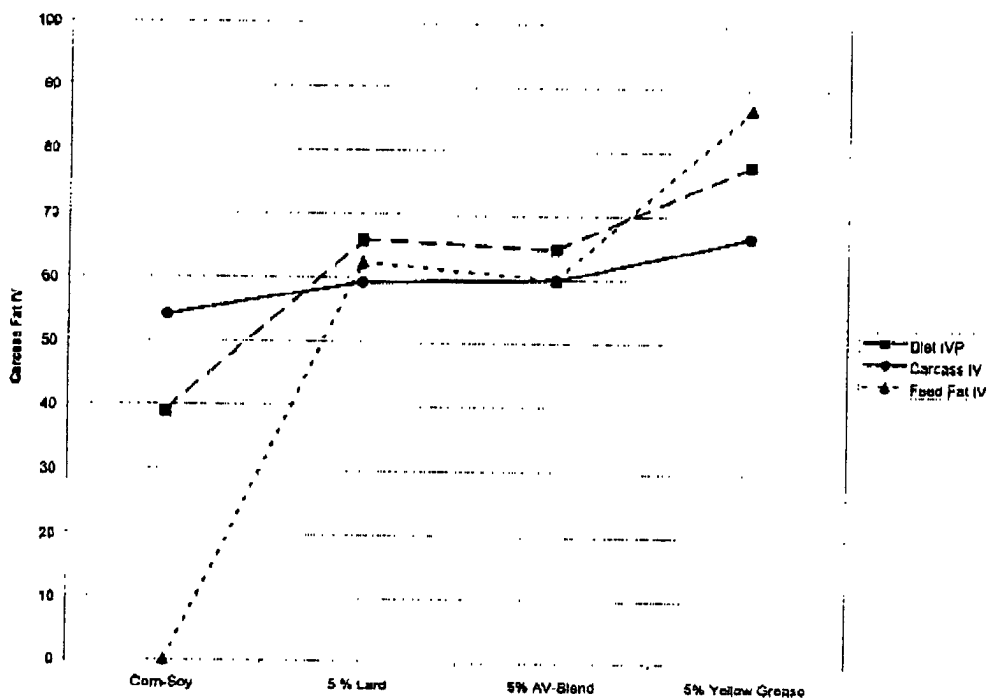
McConnell and Maurice, unpublished data

Figure 3. Relationship between Diet IVP and Carcass IV.

$$y = 0.286x + 41.783$$
$$R^2 = 0.888$$

McConnell and Maurice, unpublished data

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Figure 4. Murphy Select Genetic Run Chart.

Murphy Select Genetics Carcass IV Data
Individuals

Set 4: UCL=91.240461, Mean=81.124585, LCL=71.008710 (8/22/2001-10/24/2001) (mR=2)

Moving Range (2)

Set 4: UCL=12.430054, Mean=3.803569, LCL=none (8/22/2001-10/24/2001) (mR=2)

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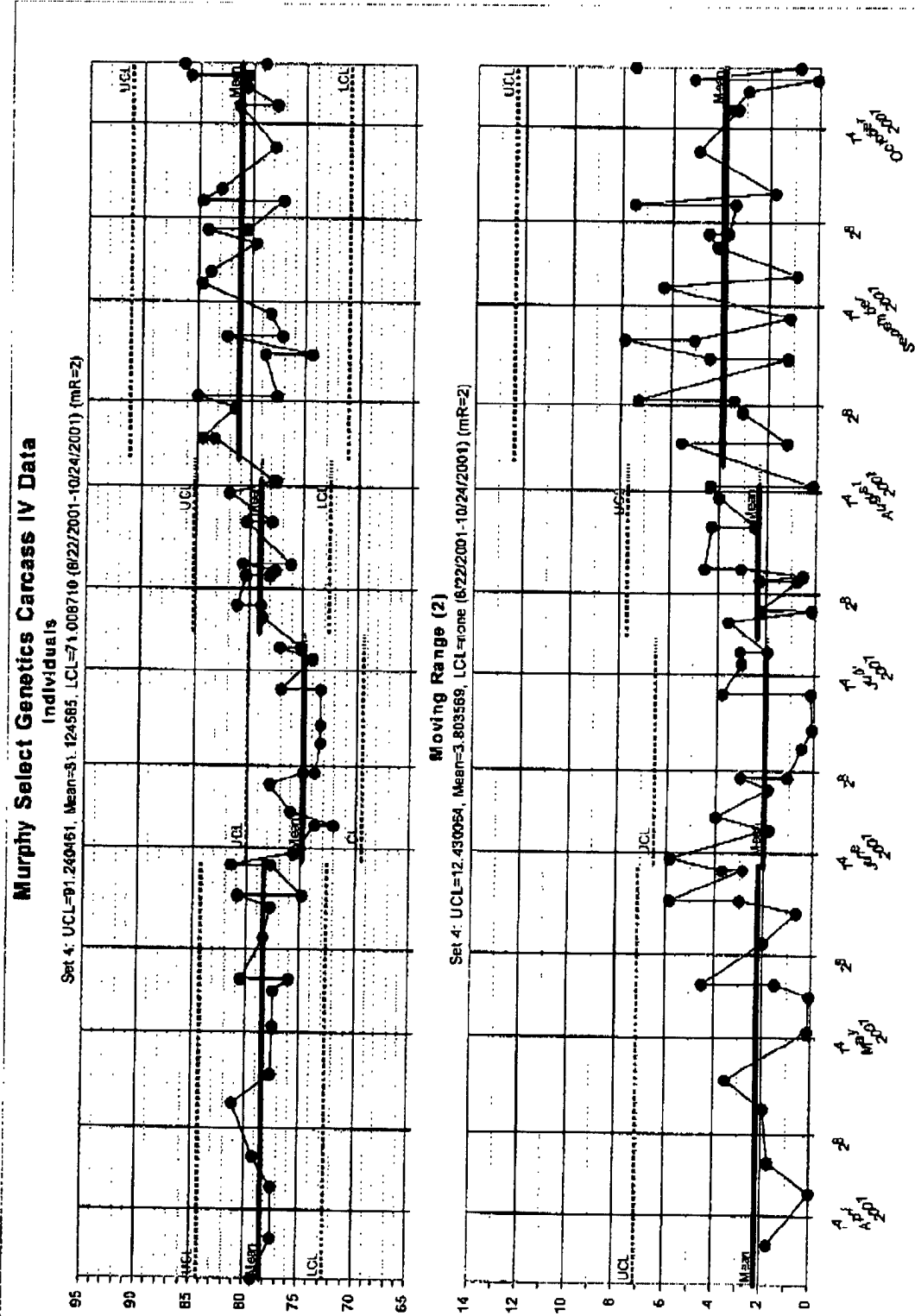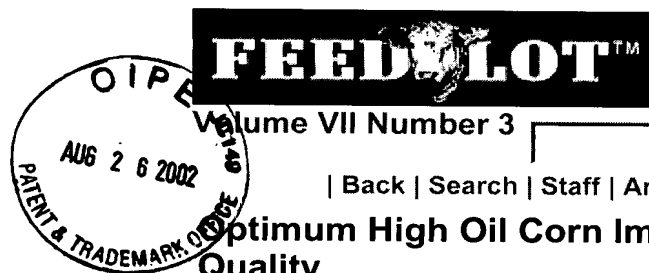
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Optimum High Oil Corn Improves Performance and Carcass Quality

Over the past decade, molecular science has developed corn grain hybrids which can increase energy and amino acid content, reduce waste management problems and improve carcass or product quality.

Although some of these hybrids are not commercially available, hybrids with higher oil content and more easily extracted starch are in the marketplace. Since their commercial release, agricultural scientists have studied how these new hybrids could affect the cattle feeding industry. And they're pleased with what they are finding.

Results of University of Idaho study
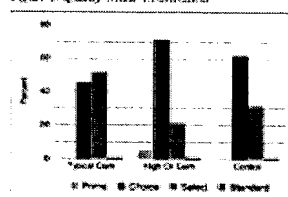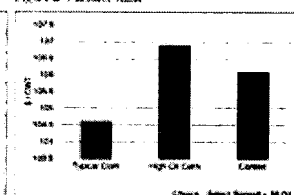
According to Optimum Quality Grains, Optimum High Oil Corn has been proven to improve growth performance and carcass quality in beef cattle.

"The success of Optimum High Oil Corn is well documented in non-ruminants, but until recently there was limited research conducted with high oil corn in beef cattle," said Dr. Steve Soderlund, Director of Beef and Dairy Business for Optimum Quality Grains.

"This past year, Optimum has collaborated with several universities and private research institutes to evaluate the effect of feeding Optimum High Oil Corn to finishing beef cattle," he said. "These feeding trials show Optimum High Oil Corn delivers greater nutritional value, better gains and improved bottom-line returns when compared with regular corn. However, the most exciting attribute we found from feeding Optimum High Oil Corn is its impact on carcass quality."

According to Optimum, the better results come in the way of improved marbling scores and carcass quality grades when compared to typical corn with no additives. In discussions with large cattle feeders, a dependable source of high oil corn was in question.

With high oil corn acres projected to exceed 1 million in the U.S. in 1999, that's some encouraging news.

According to research performed for Optimum at the University of Idaho in 1997, the carcasses from animals fed high oil corn graded over 70 percent choice compared to less than 50 percent on typical corn.

"During the past five years, USDA Choice carcasses have been worth, on the average, $5.37 per hundred weight more than carcasses graded USDA Select.

Using this average spread in carcass value, we found the value of an average carcass from a steer fed Optimum High Oil Corn was worth $5.97 to $7.91 more than a carcass from a steer fed typical corn without added fat in recent trials conducted by Iowa State University and the University of Idaho," Soderlund said.

Feeding trials from South Dakota, Iowa and Idaho demonstrate that Optimum High Oil Corn can effectively replace 100 percent of typical corn and up to three percent of added fat in finishing beef cattle diets.

The oil found in Optimum High Oil Corn is highly digestible with an energy value similar to tallow.

Several studies are currently underway to examine various rates of inclusion of high oil corn and to test additional processing methods including high moisture corn. At this time, Optimum recommends that high oil corn be processed for best utilization. Ration formulation considerations made with high oil corn should be similar to those for formulating rations containing supplemental fat.

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The Effect of Dietary Linoleic Acid on the Firmness of Backfat in Pigs of 85 kg Live Weight

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Three groups of 15 female pigs were fed diets containing 0.8%, 1.1%, or 1.8% linoleic acid from 20 to 35 kg followed by 1.0%, 1.2% or 1.4% linoleic acid respectively from 35 kg to slaughter at 85 kg live-weight. Pigs grew at similar rates on all three diets and had similar proportions of carcass fat. The mean proportions of linoleic acid in the backfat lipids were 8.6%, 11.0%, and 13.9% respectively as the amount of the diet increased. There was a significant correlation between the concentration of linoleic acid in the inner backfat lipid and P_2 backfat thickness for those animals on the high and medium linoleic acid diets but not for those on the low diet. Backfat from pigs fed the high linoleic acid diet was softer than that from the other two groups of pigs which could not be distinguished using the subjective finger probe method. Using a medium-cal probe backfat consistency was distinguished between all three groups and was inversely correlated ($r = -0.775$, $P<0.001$) with the concentration of linoleic acid in the lipid. However, none of the pigs had fat which was too soft for bacon production based on either consistency data or linoleic acid content. If 15% linoleic acid is taken to be the maximum acceptable in bacon, then extrapolation of the regression of linoleic acid concentration on backfat thickness suggested that only the 1.4% linoleic acid diet is likely to result in unacceptably soft fat as pigs become leaner. However, this high concentration, although frequently present in current feeds, is not necessary since it is twice that recommended for normal growth and development of pigs.

Keywords: Adipose tissue lipid; backfat; collagen; linoleic acid; pigs.

1. Introduction

The consistency of pig fatty tissue has been recognised to be important in meat processing and consumer acceptability. The main problem is backfat which is too soft, caused, at least in part, by high proportions of linoleic acid (C18:2) in the lipid. In recent years, this problem has become more acute as genetically leaner pigs are widely used. The concentration of linoleic acid in the backfat is related to its concentration in the diet, [2,3] and to the level of fat in the diet. [4] Leanness, produced by restriction of feed intake, also results in increased proportions of linoleic acid in the backfat. [5]

Linoleic acid however, is an essential fatty acid and, as such, must be present in the diet. The AFRC recommended dietary allowance is 3% of digestible energy (or 1.5% of dry feed) for pigs up to 35 kg and 1.5% of digestible energy (or 0.7% of dry feed) for subsequent growth.[6] Very little work has been carried out on the effect of these concentrations of dietary linoleic acid on the consistency of pig backfat in commercial animal production. Previous studies have involved use of extreme concentrations of linoleic acid, either low levels to study Essential Fatty Acid (EFA) Deficiency, or high levels in feeds to which plant oils such as peanut or sunflower oil have been added. We have therefore studied the effect on backfat consistency of three dietary concentrations of linoleic acid,

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These were chosen to encompass the concentrations found in currently produced commercial feeds and are similar or twice the level recommended by the AFRC. Furthermore, we have analysed the regression of the concentration of linoleic acid in backfat lipid on backfat thickness for the three diets to determine firstly, whether the inverse relationship between backfat thickness and its linoleic acid content is retained with the concentrations used in these diets, and secondly, at what backfat thickness soft fat is likely to occur. Differences between developmental growth patterns of fat depots and their positions within the carcass affect their fatty acid composition. We have therefore compared, and of the internal perirenal depot which normally has a more saturated fat, the shoulder and midback, and of the internal perirenal depot which normally has a more saturated fat, the dorsal subcutaneous fat.

Although feeding too much linoleic acid and its accumulation in concentrations above 15% of total fatty acids is commonly associated with softness of backfat,[1,2] the relationship of consistency to fatty acid composition is more complex. The consistency of the lipid has been shown to be the best related to the concentration of its saturated fatty acids such as palmitic and particularly stearic acid, which harden the fat as their concentration in the lipid increases.[4] Other studies have found that certain ratios of fatty acids such as monounsaturated : saturated acids and stearic : linoleic acids correlate well with firmness of adipose tissue.[9] In this study we have used animals which contain similar proportions of stearic acid in the backfat lipid, with varying concentrations of linoleic acid, to define the relationship between linoleic acid concentration and the degree of firmness of the backfat tissue.

The consistency of the carcass backfat has been assessed subjectively by the commonly used finger and thumb compression test. However, we have also used a more recently developed objective procedure which is based on the Instron materials testing instrument to remove the problem of daily variation in the performance of assessors, and differences between assessors.[10]

2. Experimental

2.1. Animals

Forty-five gilts from 30 litters, the progeny of Large White boars and Large White × Landrace ('Manor Hybrid') gilts, were used. The pigs, initially 20 kg, were raised in groups of 15 on starter diets containing 0.8%, 1.1% and 1.8% linoleic acid (per cent of dry feed) referred to as low, medium and high linoleic acid. All three diets contained 22% crude protein and 15 MJ kg⁻¹ dry matter digestible energy (DE). When the pigs reached 35 kg live-weight, they were maintained on finisher diets containing 1.0%, 1.2% and 1.4% linoleic acid (per cent of dry feed), 19% crude protein and 14 MJ kg⁻¹ DE given ad libitum for 8 weeks, after which the pigs were restricted to 2.6 kg day⁻¹. Group feed intake and weekly live-weight gain were recorded.

2.2. Slaughter and carcass measurements

At 85 kg live-weight, the animals were slaughtered and carcass weights recorded. Backfat thickness, P2, was measured 6.5 cm from the mid-line at the last rib, 45 min after slaughter. The consistency of the carcass backfat in the same region was judged subjectively after 24 h in chill (3–5°C) by pressing with the thumb and finger, on a scale of 1 (soft) to 8 (hard). A piece of backfat from over the last rib was removed and separated into inner and outer layers before measuring consistency on an Instron materials testing instrument, using a 3.5 mm dia probe and measuring the force required to penetrate the tissue to a depth of 2.5 mm at a speed of 125 mm min⁻¹. An adjacent piece of backfat was taken for fatty acid composition and tissue analysis, together with samples of shoulder fat (both layers from above the fourth rib) and perirenal fat.

2.3. Tissue analysis

Lipids were isolated from the adipose tissues by extracting freeze-dried tissue for 6 h with diethyl ether in a Soxhlet apparatus and the lipid content was determined gravimetrically after removal of the solvent. Samples of the lipid (20 mg) were saponified with 2 M potassium hydroxide in aqueous methanol (1:1, by volume) and after acidification, the fatty acids were extracted into petroleum

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spirit (b.p. 40–60°C). The fatty acids were methylated using diazomethane and were analysed by gas-liquid chromatography on a 25 m × 0.32 mm i.d. SH 88 WCOT glass capillary column (Chrompak Ltd) in a Pye 204 chromatograph with flame ionisation detection and helium as the carrier gas. Fatty acids were quantified using an Trelatronic computing integrator (LDC, Milton Roy) and each major peak was identified by comparison of retention times with those of known standards. All solvents were of analytical grade from BDH Chemicals and were distilled.

The collagen content of the fat-free dry matter was determined by hydrolysis in constant boiling hydrochloric acid (6 N) at 112°C for 24 h and then measuring the hydroxyproline content by the method of Grant.[11]

2.4. Statistical methods

Data were analysed using one-way analysis of variance, linear regression and quadratic regression. Differences between means where $P<0.05$ were considered to be significant.

3. Results

3.1. Animal growth

The fatty acid composition and lipid contents of the diets are given in Table 1. The starter diets contained 0.8, 1.1 and 1.8% linoleic acid (low, medium and high) achieved through variations in the lipid content and the fatty acid composition of the lipid. The finisher diets were lower in lipid content and contained 1.0, 1.2 and 1.4% linoleic acid as per cent of dry feed.

There were no significant differences in average daily gain, feed conversion ratio or carcass weight between the three groups of animals (Table 2). However, pigs on the high linoleic acid diet had a mean P2 value which was significantly different from those on the medium diet but not from those on the low diet which fell midway between the two former groups.

Table 1. Fat content and fatty acid composition of the diets

Dietary linoleic acid	Lipid content per cent dry feed	Fatty acids, per cent by wt[a]			
		Palmitic	Stearic	Oleic	Linoleic
Starter					
high	7.2	21.3	11.5	33.7	25.3
medium	6.5	23.0	13.9	37.3	17.4
low	5.6	23.6	14.8	38.1	14.1
Finisher					
high	4.5	19.4	9.7	32.7	31.1
medium	4.5	20.4	9.4	36.7	26.6
low	3.8	21.0	9.6	36.6	25.6

[a] Minor components by difference.

Table 2. Pig growth and carcass measurements

	Average daily gain (kg)	Feed conversion ratio (kg feed/kg gain)	Cold carcass wt (kg)	Fat thickness P2 (mm)
High (15)	0.87	2.65	67.8	14.0±0.7[a]
Medium (15)	0.87	2.74	67.6	16.0±0.8[b]
Low (15)	0.89	2.79	69.8	15.5±0.6[a,b]

Results are given as mean values or means ± s.e.m.
[a,b] Numbers within columns with different superscripts differ significantly, $P<0.05$.
Numbers of animals in parentheses.

3.2. Backfat consistency

When assessed subjectively, none of the pigs displayed unacceptably soft fat, the average score of 4.39 falling between the two extremes of the subjective scale of 1 (soft) to 8 (hard). When assessed by the subjective finger test backfat from the pigs fed on the high linoleic acid diet was significantly softer than that of pigs fed either the medium or low diets (Table 3). There was no difference in consistency between those on either the medium or low linoleic acid diet as assessed by this method.

By comparison, the mechanical probe was able to detect significant differences in consistency in the inner layer between all three groups. The higher the concentration of dietary linoleic acid, the less was the force required to penetrate the tissue to a depth of 2.5 mm. Firmness measurements in the outer backfat layer were similar to those found in the inner layer, but due to the greater variability in pigs fed on the low linoleic acid diet, the difference was only significant between those on the high and low diets.

3.3. Adipose tissue composition

There were no differences in tissue composition between pigs on different diets, except for small differences in the backfat at the last rib (Table 4). The inner backfat from animals on the high linoleic acid diet had a significantly lower fat content on a wet weight basis, when compared with those on the medium diet. However, the animals on the low linoleic acid did not differ from those on either the high or medium diet.

Results are expressed as mean values ± s.e.m. for 15 animals in each group.
a,b,c Numbers within columns for each site with different superscripts differ significantly, P<0.05.

Table 3. Assessment of backfat consistency

Dietary linoleic acid content of the diet	Subjective finger test (1 soft–8 hard)	Instron probe force, 2.5 mm (kg force)
Backfat inner		
high	3.7±0.17	0.26±0.09
medium	4.6±0.29	0.39±0.05
low	4.87±0.19	0.56±0.09
Backfat outer		
high		0.29±0.05
medium		0.39±0.05
low		0.50±0.19

Table 4. Effect of dietary linoleic acid on tissue composition of backfat

Dietary linoleic acid	Percent of wet weight		
	Water	Fat	Collagen
Backfat inner			
high	12.5±0.9	78.4±1.1	2.6±0.3
medium	13.5±0.8	81.9±1.1	1.9±0.1
low	14.1±0.7	80.2±0.7	2.2±0.1
Backfat outer			
high	13.7±0.3	79.0±1.3	3.7±0.3
medium	14.2±0.8	79.1±1.3	3.7±0.4
low	13.0±0.5	80.1±0.7	3.2±0.3

Mean values ± s.e.m. 15 animals in each group.
a,b Numbers with different superscripts within columns for each site differ significantly, P<0.05.

The backfat also showed some significant differences in collagen content between the three groups of animals (Table 4). For the inner layer, those on the high diet contained significantly more collagen as a percentage of wet weight than those on the medium diet, and those on the low diet fell midway between the higher and medium groups. For the outer layer, the proportion of collagen did not differ between those pigs on the high and medium linoleic acid diets, but both groups of animals had significantly higher proportions than those on the low diet. The outer layer contained a greater proportion of collagen than the inner in all three groups.

3.4. Fatty acid composition of the adipose tissue lipid

The six major fatty acids which constitute >98% of the total fatty acids were isolated from the three depots (Table 5). In both layers of backfat all three groups of pigs had significantly different proportions of linoleic acid, the concentration increasing in line with dietary concentration of linoleic acid. The differences in proportions of the other fatty acids between groups were much less than those for linoleic acid. Oleic was the next most affected, its concentration declining as dietary linoleic acid increased.

The effect of dietary linoleic acid on its concentration in fat tissue was also found in both layers of shoulder fat where the results were very similar to those found at the midback, but with higher concentrations of linoleic acid.

Analysis of the perirenal adipose tissue revealed higher concentrations of the saturated fatty acids, palmitic and stearic, characteristic of this internal depot. Once again, the proportions of linoleic acid in the tissue reflected the differing concentrations of dietary linoleic acid and were significantly different between all three treatment groups. In the shoulder and perirenal fat, as in the midback, the increase in tissue linoleic acid was accompanied by a small decrease in the proportions of palmitic and oleic acids with very little difference in stearic acid.

As previously reported, the outer layer of backfat, both at the fourth and last rib positions, contained a higher proportion of linoleic acid and lower portion of stearic acid than the inner layer.

Table 5. Fatty acid composition of adipose tissue

Dietary linoleic acid	Fatty acids, per cent by weight¹ of total fatty acids				
	Palmitic	Palmitoleic	Stearic	Oleic	Linoleic
Backfat inner					
high	24.3±0.5ᵃ	1.3±0.1ᵃ	12.4±0.3	42.8±0.5ᵃ	13.9±0.4ᵃ
medium	25.0±0.4ᵃ·ᵇ	1.3±0.1ᵃ	12.8±0.6	44.5±0.5ᵇ	11.0±0.4ᵇ
low	26.0±0.3ᵇ	1.6±0.1ᵇ	12.9±0.3	45.9±0.5ᵇ	8.6±0.4ᶜ
Backfat outer					
high	21.9±0.3ᵃ	2.9±0.1ᵃ	9.5±0.3	41.4±0.5ᵃ	16.6±0.5ᵃ
medium	21.0±0.2ᵃ	3.0±0.1ᵃ·ᵇ	9.9±0.4	47.8±0.3ᵇ	13.8±0.4ᵇ
low	22.0±0.3ᵃ	3.2±0.1ᵇ	10.0±0.3	49.5±0.3ᶜ	11.2±0.3ᶜ
Shoulder inner					
high	22.1±0.4ᵃ	2.5±0.1ᵃ	12.5±0.3	43.1±0.4ᵃ	15.4±0.5ᵃ
medium	23.2±0.4ᵃ	2.6±0.1ᵃ·ᵇ	13.0±0.4	45.4±0.4ᵇ	12.0±0.3ᵇ
low	23.9±0.3ᵃ	2.8±0.1ᵇ	13.2±0.3	46.7±0.3ᵇ	9.5±0.2ᶜ
Shoulder outer					
high	23.0±0.3ᵃ	2.6±0.1ᵃ	10.8±0.2	41.4±0.5ᵃ	14.9±0.5ᵃ
medium	22.9±0.4ᵃ	3.6±0.1ᵇ	11.1±0.4	42.6±0.4ᵇ	13.1±0.3ᵇ
low	24.4±0.2ᵇ	3.2±0.1ᵇ	11.1±0.2	44.9±0.5ᶜ	10.5±0.2ᶜ
Perirenal					
high	27.4±0.3ᵃ	2.1±0.1	16.6±0.3	36.3±0.5ᵃ	11.4±0.5ᵃ
medium	27.7±0.3ᵃ·ᵇ	2.3±0.1	17.1±0.1	39.0±0.4ᵇ	10.1±0.3ᵇ
low	28.4±0.3ᵇ	2.4±0.1	17.5±0.4	39.6±0.4ᵇ	8.9±0.3ᶜ

¹ Minor components to 100%.
Mean values ± s.e.m. 15 animals in each group.
a,b,c Numbers within columns with different superscripts differ significantly, P<0.05.
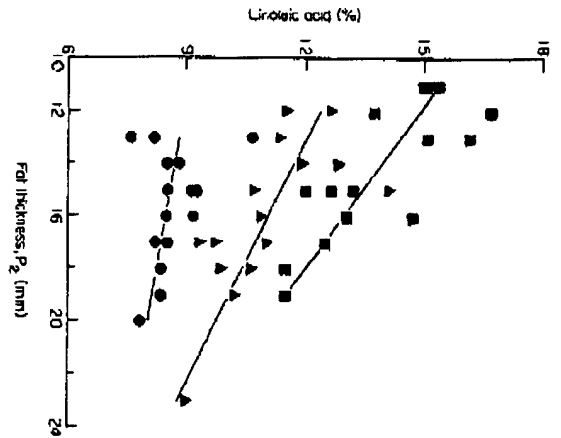
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Figure 1. Relationship between P_2 fat thickness and the proportion of linoleic acid in lipid of inner backfat in pigs fed high (■) ($y=20.1-0.482x; r=-0.76, P<0.01$), medium (▲) ($y=16.4-0.335x; r=-0.70; P<0.01$), and low (●) linoleic acid diets ($y=10.2-0.104x; r=-0.32;$ not significant).

Figure 2. Relationship between probe force at 2.5 mm (N) and the ratio of stearic to linoleic acid in lipid of inner backfat in pigs (■), high; (▲), medium; (●), low linoleic acid diet ($y=0.728+1.17x; r=0.775; P<0.001; n=45$).

3.5. Relationship between linoleic acid and fat thickness

Since previous work had shown that the concentration of linoleic acid is affected by fat thickness as well as diet, the relationship between linoleic acid concentration and P_2 fat thickness was examined for each diet group separately in the backfat inner layer (Figure 1). In each case as fat thickness increased the proportion of linoleic acid decreased with both the high and medium diets but not for those on the low diet. The regression was significant for animals on the high and medium diets but not for those on the low diet.

3.6. Effects of fatty acids and tissue constituents on fat firmness over all groups

Correlations between fat firmness (measured using the Instron materials testing instrument) and fatty acid concentrations are shown in Table 6. In addition to individual fatty acids, certain combinations and ratios of fatty acids were used, which have been previously implicated as determinants of consistency as measured by melting or slip points, or subjective assessment.

Table 6. Regression analysis of the relationship of fatty acid composition to the probe force at 2.5 mm (N) over all treatments for backfat inner layer

Independent variable	Regression equation[a] where dependent variable r is the probe force (N)	Correlation coefficient (r)
Palmitic	$23.6+3.70x$	$0.49***$
Stearic	$11.3+3.29x$	$0.54***$
Oleic	$43.3+3.06x$	0.29
Linoleic	$14.6-18.53x$	$-0.73***$
M/S[b]	$1.3-0.192x$	$-0.33*$
Palmitic+stearic	$34.9+7.02x$	$0.62***$
Stearic/linoleic	$0.728+1.17x$	$0.78***$
Collagen per cent on wet weight	$2.98-1.64x$	$-0.49***$

[a] $y=a+bx$ where $a=$ intercept, $b=$ slope (number of animals $=45$).
[b] M/S=monoenoic/saturated acid ratio.
* $P<0.05;$ ** $P<0.01;$ *** $P<0.001.$

The individual fatty acid which correlated best with probe force in the inner layer of backfat (last ab position) was linoleic acid, followed by stearic and palmitic acid. The monounsaturated: saturated acid ratio was only just significantly correlated to probe force. A combination of palmitic and stearic acids on the regression against probe force improved on their individual correlation coefficients but it was found that the best correlation was between the ratio of stearic: linoleic acid and mechanical probe force (Figure 2). However, analysis of the residual and fitted values suggested that the relationship was not truly linear and a quadratic regression was used:

$$y=0.342+3.33 \text{ (probe force)} -2.34 \text{ (probe force)}^2$$

The correlation coefficient increased from $r=0.78$ to $r=0.84$, thus confirming that the relationship is not truly linear.

There was an inverse relationship between collagen content and mechanical probe force which was significant, only for the inner layer. For the outer layer of backfat there was no significant relationship, $y=3.14-1.05x, r=-0.179.$
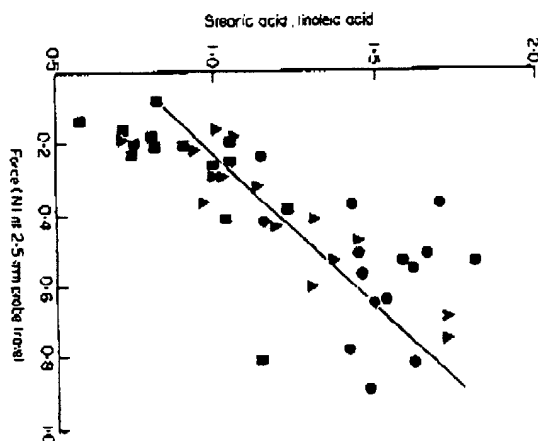
4. Discussion

4.1. Dietary linoleic acid and animal growth

Within the range of dietary concentration of linoleic acid used, there were no significant differences in carcass weight, average daily gain or feed conversion ratio, indicating that the lowest quantity fed was adequate for normal growth and development of the weaning pig as recommended by the AFRC.[6] The animals fed on the high linoleic acid diet had a lower P_2 value suggesting lower carcass fat but there appeared to be no general trend towards increasing fatness as dietary linoleic acid was reduced. Further experiments would be required to determine whether this was a 'real' effect of treatment.

4.2. Fatty acid composition and consistency of adipose tissue

As expected, the proportions of linoleic acid deposited in the lipid at the three sites reflected the concentration of dietary linoleic acid—significantly so for all three treatments. The concentrations of

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linoleic acid in the perirenal lipid were very similar to those found in the inner layer of backfat although the concentrations of saturated fatty acids were characteristically higher in the perirenal depot. The relative proportions of linoleic acid in the inner layer of shoulder fat were higher than those found in the backfat; however, the reverse was true for the outer layers. The mean concentration of stearic acid in all three sites remained unchanged with increasing dietary linoleic acid. At this live-weight therefore, the different rates of development of the three sites studied has not resulted in a markedly different distribution of linoleic acid in the lipid. When grown to bacon weight, none of the pigs displayed unacceptably soft fat, even when fed at twice the recommended concentration of dietary linoleic acid. These animals on the high linoleic acid diet contained 13.9% linoleic acid in the lipid of the inner layer of backfat, and had a P_2 fat thickness of 14 mm. While under these conditions the fat was considered acceptable in appearance and texture, regression analysis showed that a tendency to develop soft fat would become more likely if genetically leaner pigs were used, or if the diet was restricted in order to reduce backfat thickness to about 12 mm. Extrapolation of the analysis also indicated that these animals, fed on the medium and low linoleic acid diets (both still above recommended concentrations) would not produce soft fat unless P_2 fat thickness was reduced to about 5 mm.

4.3. Measurement of consistency and its relationship to tissue constituents and fatty acid composition

The results have shown that the mechanical probe was the more discriminating method in detecting differences in consistency of backfat between the three groups of pigs—in line with the presence of differences in fatty acid composition—when compared with the subjective fingertest. These results agree with others collected at this Institute.[9]

The contribution of collagen concentration to the consistency of backfat is not clear; there was a significant inverse relationship between collagen content and probe force for the backfat inner layer although the correlation coefficient ($r = -0.494^{***}$) was low when compared with that of the stearic:linoleic acid ratio ($r = 0.78^{***}$). However, although there was a higher proportion of collagen in the outer layer, the concentration was not significantly related to probe force ($r = -0.178$).

It has been reported that the distribution of saturated and unsaturated fatty acids within the triglyceride structure affects the consistency of adipose tissue,[12] and previous work suggested that there was a tendency to replace saturated fatty acids such as a palmitic and stearic on the 1 and 3 hydroxyl positions with linoleic acid as the concentration of this fatty acid increases in the lipid.[9] Thus it may be the positional relationship or substitution of stearic with linoleic acid within the triglyceride structure which plays an important part in determining the consistency of adipose tissue under these conditions.

The increased proportions of linoleic acid and lower proportions of stearic acid found in the outer layer of the subcutaneous fat, when compared with the inner layer, would be expected to result in a lowering of the force required to penetrate the tissue since the lipid in the outer layer is reported to have a lower melting point than the lipid in the inner layer.[7] However, the probe forces were very similar for both layers in all three groups of pigs. The contribution of changes in the concentration of stearic acid and linoleic acid to the probe force were similar in the two layers since regression analysis revealed almost parallel lines. This was most clear for stearic acid where the regressions were $y = -0.543 + 0.0957x$ for the outer layer and $y = -0.727 + 0.0892x$ for the inner layer. The difference in the intercept represents a probe force of approximately 0.25 N. For linoleic acid the regressions were outer layer $y = 1.10 - 0.508x$, inner layer $y = 1.10 - 0.062x$. Although the effect is less clear cut because of the lack of a difference in the intercepts, the differences in probe force over the range of linoleic acid from 9% to 16% in this study was 0.1 N to 0.18 N. The most likely cause of this constant increase in the resistance to penetration of the outer layer compared with the inner layer is likely to be its 58% higher collagen content although differences in the three-dimensional arrangement of the collagen may also be present.

When analysing the contribution of individual fatty acids to the firmness of the tissue across the treatments, there was the expected inverse relationship between linoleic acid and probe force, whereas stearic and palmitic acids were positively related to the probe force. Our previous work has also shown that linoleic acid and stearic acid are the most significant fatty acids affecting fat firmness

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and melting point respectively.[9] While the mean concentration of stearic acid in the backfat lipid did not differ significantly between the three groups, the ratio of stearic: linoleic acids produced the best prediction of probe force. The effectiveness of the quadratic equation in predicting firmness indicates that the relationship between fatty acid composition and firmness of adipose tissue is more complex than first considered.

This study has shown that feeding linoleic acid in the diet at twice the recommended concentration did not adversely affect the growth of the pigs, or result in unacceptably soft fat. However, extrapolation of the regression suggests that if genetically leaner pigs were used, or if the level of feeding of the high linoleic acid diet was restricted in order to reduce backfat thickness below 11 mm, soft fat could result. For animals fed on the medium and low linoleic acid diets, both still above recommended concentrations, soft fat would result only if P_2 fat thickness was reduced to about 5 mm.

When relating the fatty acid composition of the backfat to the consistency of the tissue, it was found that linoleic acid was the best individual fatty acid which correlated significantly with probe force. Although the mean stearic acid concentrations in the lipid were not different between the three groups, this fatty acid was also significantly correlated with probe force. However, the best predictor of probe force was the ratio of stearic:linoleic acid in a quadratic regression, which indicated that the relationship was not linear.

Comparison of the mechanical test probe with the subjective finger test showed the former method to be a more sensitive discriminator of backfat consistency.

Acknowledgements

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The effects of dietary fat sources, levels, and feeding intervals on pork fatty acid composition[1]

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ABSTRACT: Two experiments investigated the quantitative relationship between dietary fat and fatty acid composition of pork. Experiment 1 was designed to establish the rate of decline for linoleic acid and iodine value of pork fat during the late fattening phase following a dietary reduction. Gilts (n = 288) were fed diets varying in linoleic acid content from 4.11 to 1.56% for 4, 6, or 8 wk prior to slaughter. The maximum rate of decline was 2% 18:2 per week and 2.5 iodine value units per week. Experiment 2 evaluated the effects of dietary fat source and level on carcass fatty acid composition and on pork quality characteristics. Barrows (n = 147) and gilts (n = 147) were allocated to seven dietary treatments for the last 6 wk of the finishing phase. Diets contained 0, 2.5, or 5% dietary fat comprised of 100, 50, or 0% beef tallow. The balance was provided by animal-vegetable blended fat. As the level of tallow increased there was a linear decrease ($P < 0.05$) in 18:2 content and iodine value of carcass fat. Conversely, 16:1 and 18:1 increased linearly ($P < 0.05$) as tallow increased. However, 16:1 decreased linearly ($P < 0.05$) as level of fat increased. As the level of tallow was increased a greater reduction in 18:2 and iodine value was observed in diets with 5% dietary fat compared to diets with 2.5% fat ($P < 0.05$). These results indicate that reduction of dietary PUFA content had the desired effect of lowering 18:2 content and iodine value of pork fat and that significant alterations could be elicited in as little as 6 to 8 wk of feeding.

Key Words: Pigs, Carcass Quality, Fatty Acids, Supplemental Fat, Linoleic Acid

Introduction

As the pork industry strives for efficient production of increasingly leaner pigs, reduction in fat quality can occur that may adversely affect further processing, tissue separation, and storage stability. Combining extreme leanness in the pig with diets composed of cereal grains and supplemented with fat, often high in polyunsaturated fatty acids (PUFA), in order to maximize grow-finish performance and efficiency can result in soft pork fat. These pork production techniques do help to realize consumer demands for reduced total carcass fat and saturated fatty acids, but this is in conflict with the optimal physical qualities of fat desired for further processing. Consistency and composition of pork fat are quality concerns (Morgan et al., 1994), because thin bellies and soft fat produce more miscuts and a higher percentage yield of lower-quality product.

It is well established that the fatty acid composition of pork is influenced by the composition of dietary fat (Seerly et al., 1978; Madsen et al., 1992; Miller et al., 1990); however, the quantitative relationship has not been well defined, especially in lean genotype pigs. However, it has been demonstrated (Scott et al., 1983) that there are more saturated fatty acids present in the fat depots of pigs with a genetic predisposition for obesity than in pigs selected for reduced backfat thickness. Wood (1984) reported that PUFA were increased in pigs when fat deposition was reduced by limit feeding as compared to ad libitum intake. The goal of this study was to evaluate nutrition and management programs for lean genotype pigs to maintain production while enhancing pork fat quality. Specifically, our objective was to determine the quantitative relationship between dietary fat and the pork fatty acid profile by manipulating dietary unsaturated fatty acids. This was achieved by reducing linoleic acid content or varying dietary fat sources and levels.

Materials and Methods

Experiment 1 Design. Market gilts (n = 288) from PIC 406 sires × PIC C22 dams were delivered to the North

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Table 1. Composition of diets in Exp. 1 (as-fed basis)

Item	Soy oil, %			
	100	66.7	33.3	0
Ingredient, %				
Corn	76.10	76.10	76.10	76.10
Soybean meal (48% CP)	16.60	16.60	16.60	16.60
Soy oil	5.00	3.33	1.67	—
Hydrogenated fat	—	1.67	3.33	5.00
Limestone	0.95	0.95	0.95	0.95
Dicalcium phosphate, 21%	0.69	0.69	0.69	0.69
Salt	0.38	0.38	0.38	0.38
Lysine-HCl, 95%	0.13	0.13	0.13	0.13
Trace mineral premix[a]	0.05	0.05	0.05	0.05
Vitamin premix[b]	0.05	0.05	0.05	0.05
Virginiamycin 20	0.025	0.025	0.025	0.025
Selenium premix[c]	0.025	0.025	0.025	0.025
Calculated composition				
Linoleic acid, %	4.11	3.26	2.41	1.56
Crude protein, %	14.2	14.2	14.2	14.2
Lysine, %	0.82	0.82	0.82	0.82
Phosphorus, %	0.46	0.46	0.46	0.46
Calcium, %	0.58	0.58	0.58	0.58

[a]Provided the following per kg of mix: 166.7 g Zn as ZnO, 166.7 g Fe as $FeSO_4$, 28.3 g Mn as MnO, 20.2 g Cu as $CuSO_4$, 70 mg I, and 30 mg Se.

[b]Provided the following per kg of mix: 2,268 kIU vitamin A, 340 kIU vitamin D, 9,072 IU vitamin E, 1,134 mg vitamin K, 8.2 mg vitamin B_1, 1,361 mg riboflavin, 6,350 mg d-pantothenate, 9,072 mg niacin, and 2,749 mg menadione.

[c]Each kg provided 600 mg Se.

Carolina Swine Evaluation Station at 62 kg and allowed 1 wk to acclimate. Animals were fed the 100% soy oil diet for 3 wk prior to allotment (avg 80 kg) to a 4 × 3 factorial design, blocked by initial weight. Pigs were fed one of four diets varying in polyunsaturated fatty acid (PUFA) content for 4, 6, or 8 wk prior to slaughter. All diets (Table 1) contained 5% added fat, comprised of 100, 66.7, 33.3, or 0% soy oil (Cargill, Fayetteville, NC). The balance was provided by a fully hydrogenated animal fat (Patrick Cudahy, Cudahy, WI). Fatty acid composition of the supplemental fat sources is described in Table 2. Carcass data were obtained from 96 pigs in each slaughter group.

Experiment 2 Design. Barrows (n = 147) and gilts (n = 147) from a PIC 406 sire × PIC C22 female cross were delivered to the North Carolina Swine Evaluation Sta-

tion and allowed a 1-wk period to acclimatize to the facility. Pigs (avg 80 kg) were blocked by initial weight and randomly assigned to one of seven dietary treatments. Dietary treatments (Table 3) varied in percentage dietary fat and dietary fat type and were fed for 6 wk prior to slaughter. Diets contained 0, 2.5, or 5% dietary fat comprised of 0, 50, or 100% beef tallow. The balance was provided by an animal-vegetable fat blend (Table 2).

Live Animal Care and Measurements. All animal procedures were approved by the Institutional Animal Care and Use Committee of North Carolina State University. Pigs and feeders were weighed at 2-wk intervals and feed allotments were weighed daily to determine ADG, ADFI, and feed:gain. Pigs were housed three per pen in a naturally ventilated confinement building with solid concrete floors with 5.6 m^2 per pig. Feed and water were

Table 2. Analyzed fatty acid composition of the fat sources used in exp. 1 and 2

Fatty acid	Soy oil	Hydrogenated fat	Animal-vegetable	Tallow
16:0, %[a]	10.50	30.12	17.69	24.78
18:0, %	3.20	56.61	10.43	20.92
18:1, %	22.30	2.00	35.03	35.41
18:2, %	54.50	0.39	34.67	6.02
18:3, %	8.30	ND[b]	ND	ND
Other[c]	1.20	10.88	2.18	12.87
Iodine value	132.00	2.50	97.50	41.00

[a]Percentage by weight.
[b]ND = not detected.
[c]Comprised of 3% or less of each of the following fatty acids including: 8:0, 10:0, 12:0, 14:0, 14:1, 15:0, 16:1, 20:0, 20:1, and 20:2.

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Table 3. Composition of diets in Exp. 2 (as-fed basis)

Item	Control	2.5AV	2.5B	2.5T	5AV	5B	5T
Ingredient, %							
Corn	80.85	77.06	77.06	77.06	73.22	73.22	73.22
Soybean meal (48% CP)	16.65	17.95	17.95	17.95	19.30	19.30	19.30
Tallow	—	—	1.25	2.50	—	2.50	5.00
Animal-vegetable blend	—	2.50	1.25	—	5.0	2.50	—
Limestone	1.04	1.04	1.04	1.04	1.04	1.04	1.04
Dicalcium phosphate, 21%	0.77	0.77	0.77	0.77	0.76	0.76	0.76
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Lysine-HCl, 95%	0.136	0.139	0.139	0.139	0.142	0.142	0.142
Trace mineral premix[b]	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Vitamin premix[c]	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Virginiamycin 20	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Selenium premix[d]	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Calculated composition							
Diet iodine value	124.0	113.6	101.9	90.3	108.7	91.9	75.2
Linoleic acid, %	1.85	2.64	2.28	1.92	3.44	2.71	1.99
Crude protein, %	14.6	14.9	14.9	14.9	15.2	15.2	15.2
Lysine, %	0.84	0.87	0.87	0.87	0.91	0.91	0.91
Phosphorus, %	0.48	0.48	0.48	0.48	0.48	0.48	0.48
Calcium, %	0.62	0.62	0.62	0.62	0.62	0.62	0.62
ME, kcal/kg	3,328	3,447	3,440	3,434	3,565	3,553	3,540

[a]Treatment abbreviations are defined by the amount (2.5 = 2.5%; 5 = 5.0%) and source of supplemental fat: AV = animal-vegetable blend; B = animal-vegetable + tallow blend; T = tallow.

[b]Provided the following per kg of mix: 166.7 g Zn, 166.7 g Fe, 28.3 g Mn, 20.2 g Cu, 70 mg I, and 30 mg Se.

[c]Provided the following per kg of mix: 2,268 kIU vitamin A, 340 kIU vitamin D, 9,072 IU vitamin E, 1,134 mg vitamin K, 8.2 mg vitamin B_1, 1,361 mg riboflavin, 6,350 mg d-pantothenate, 9,072 mg niacin, and 2,749 mg menadione.

[d]Each kg provided 600 mg Se.

available for ad libitum consumption. During the course of the experiments six pigs were removed from Exp. 1 and four pigs were removed from Exp. 2 because of death or failure to thrive.

Adipose tissue samples were collected 3 wk prior to allotment (Exp. 1) and on the day of allotment (Exp. 1 and 2) from one pig per pen by biopsy for fatty acid analysis. Lidocaine (2%, Vet Tek, Blue Springs, MO) was administered as a local anesthetic prior to biopsy. Biopsies were taken with a spring-loaded biopsy device (Biotech Ltd., Slovakia) while animals were restrained in a working chute. The biopsy location was at the 10th rib, approximately 5 cm from the backbone and 2.5 cm deep. Animals were treated with an iodine wound spray after removal of the sample and monitored for signs of infection. Samples were stored under N_2 gas at −80°C until analysis. All other adipose tissue samples were obtained from each pig at slaughter.

Carcass Measurements. All animals were slaughtered in a large commercial facility. Hot carcass weight was determined on-line. Backfat depth and loin muscle depth were measured and lean percentage predicted with the Fat-O-Meater optical probe (SFK Technology A/S, Denmark). Fat-O-Meater measures were taken through a section of the longissimus dorsi between the 3rd and 4th last rib 7 cm off the mid-line split. Carcasses were chilled for 24 h, at which time a 2.5-cm chop was removed between the 9th and 10th ribs. After allowing a minimum of 20 min bloom time, each chop was evaluated for color, ultimate pH, and temperature. The loin chop was mea-

sured in triplicate (middle, medial, and lateral) and mean values were calculated for color lightness (L*), redness (a*), and yellowness (b*) using a Minolta Chromameter 200 (Minolta, Ramsey, NJ). The chromameter was set to D65 illuminant, a 2° standard observer, using an 8-mm optical port with glass insert, and calibrated with Minolta white standard color plate. A visual color score was also determined on a scale from 1 to 6 (1 = pale, 6 = very dark) using plastic Japanese color standards. Japanese color standards are closely related to the Minolta L* value but the scales are in the opposite direction. A lower Minolta L* value indicates a darker color. On the same sample, ultimate pH was measured using an Engold electrode and a K21 pH meter (NWK Binar, Landsberg, Germany). A comparison test of belly firmness (stick test) was conducted by measuring the distance between the outside edges of a belly draped across a smokehouse stick.

Percentage drip loss was estimated by hanging a 100-g loin section removed from between the 9th and 10th rib in a bag for the period from 24 h to 36 h postmortem. The loin section was then reweighed and purge loss was determined.

Backfat tissue cores were taken from each pig from a location approximately 10 cm below the last rib at the midline. Fat samples were placed in N_2 gas at the time of collection and sample preparation and analysis began within 120 min of collection.

Fat firmness was measured using the compression test on the Instron machine. A 1.27-cm core sample was re-

·moved from the belly, weighed, and maintained at 4°C until analysis. The sample was compressed to 80% of its original height and the force (kg/g) of compression was determined. The melting point of carcass fat samples was determined using the capillary tube method (AOCS, 1998).

Tissue Analysis. The adipose tissue core samples included the upper layer, middle layer, and the lower layer (including the fascia above the muscle). Following removal of the skin and muscle tissue from the core, the remaining tissue was minced and mixed thoroughly. Lipids were isolated from adipose tissue in duplicate by weighing 100 mg into a glass tube with a Teflon-lined cap. One milliliter of a reagent containing 3.75 M NaOH dissolved in a 1:1 (vol/vol) methanol, distilled water mixture was added and the tubes were heated in a boiling water bath for 5 min, vortexed, and returned to the water bath for 25 min. The samples were then placed into cool water and 2 mL of a 1.7:1 (vol/vol) methyl alcohol and 6.0 N hydrochloric acid mixture was added. The samples were placed into the boiling water bath for 10 min and then immediately placed in cool water. Three milliliters of a 1:1 (vol/vol) methyl tert-butyl ether and hexane mixture was then added to the samples. Samples were vortexed and mixed continuously for 10 min until they were clear and the lower, aqueous phase was discarded. Finally, 3 mL of 0.3 M NaOH was added to the remaining organic layer and the tubes were mixed and centrifuged. Two-thirds of the top, organic, layer was removed to a clean vial and dried under N_2 gas. The methyl esters were redissolved in 250 μL of hexane. A Hewlett Packard 5890 gas chromatograph (Hewlett Packard, Avondale, PA) equipped with a flame ionization detector was used with a 100-m fused silica capillary column with an i.d. of 0.25 mm, a 0.20 μm film coating, and a SP-2380 column stationary phase (Supelco, Bellefonte, PA). Operating conditions were as follows: helium carrier gas, split ratio 1:100, injector temperature 220°C, detector temperature 220°C, initial oven temperature 140°C increasing to 225°C at a rate of 3.2°C/min. The oven was held at 225°C for 14 min, then temperature increased by 2°C/min to 230°C and was held for 6 min. Finally, the temperature was decreased by 8°C/min to 140°C and held for 4 min. Total run time was 65 min. Methyl ester standards were used to identify sample fatty acid methyl esters. Integration software (Millenium, Waters Inc.) was used to calculate the proportion of each fatty acid present. Iodine value was calculated using the following equation: iodine value = 16:1 (0.95) + 18:1 (0.86) + 18:2 (1.732) + 18:3 (2.616) + 20:1 (0.785) + 22:1 (0.723) (AOCS, 1998).

Statistical Analysis. All analyses were conducted using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC). Least squares treatment means were obtained assuming fixed models that included the effects of block, diet, time, and diet × time for Exp. 1.

For Exp. 2, least squares treatment means were obtained assuming fixed models that included the effects of block, sex, fat type, percentage of dietary fat, sex × fat type interaction, and sex × percentage dietary fat

interaction. For Exp. 2 the diet degrees of freedom (df) were partitioned into contrasts for linear and quadratic effect of dietary fat level, linear and quadratic effects of dietary fat source, and dietary fat level × dietary fat source interaction. Sex × diet interaction degrees of freedom were partitioned into contrasts for the sex × dietary fat level interaction and the sex × dietary fat source interaction. Fat source, fat level, and interaction least squares means were estimated using a linear function of the model parameters (SAS Inst., Inc., Cary, NC).

Results

Experiment 1

As soy oil was replaced with saturated animal fat, growth rate was unaffected but feed intake from 0 to 8 wk and feed:gain from 0 to 6 wk increased linearly ($P < 0.0001$, Table 4). Combined with data from a digestibility study (Averette Gatlin et al., 2002), these data suggest that the saturated animal fat was not well-digested. No effects of dietary fat composition were detected on final live weight, carcass weight, fat or loin depth, lean percentage, drip loss (Table 5), dressing percentage, pH, loin color (except A reading), or belly color (data not shown). However, a negative quadratic effect ($P < 0.05$) of diet on the loin Minolta-A reading (data not shown) was observed, but this is of questionable biological significance. Both fat depth and loin depth increased with increased time on dietary treatment (linear and quadratic time effect; $P < 0.05$). However, lean percentage decreased linearly ($P < 0.05$) with increased time on dietary treatment. As the PUFA content of the diet was reduced, there was a linear decrease ($P < 0.05$) in 18:2 content of carcass fat. Linoleic acid content also decreased linearly over time ($P < 0.05$). Due to a diet × time interaction, reducing PUFA content reduced iodine values only in gilts fed diets for 6 or 8 wk, but not in those fed for 4 wk. In addition, iodine value decreased linearly only for diets containing 33.3 or 0% soy oil but not for those containing 100 or 66.7% soy oil. The maximum rate of decline (2% 18:2 per week and 2.5 iodine value units per week) was exhibited by gilts fed the diet containing 0% soy oil (diet × time interaction, $P < 0.05$). Conversely, 16:1 and 18:1 increased as the PUFA content of the diet was decreased. For monounsaturate content, the rate of change was greatest for the diet containing 0% soy oil (diet × time interaction, $P < 0.05$). The monounsaturates increased quadratically (positive) with time ($P < 0.05$). No effects on 20:1 content or stick test were detected ($P > 0.10$). Analysis of fatty acid composition of backfat biopsy samples (Figure 1) indicated that 18:2 concentration remained unchanged during the 3-wk pretest period, averaging about 25%. The collective time course of changes in 18:2 concentration throughout the experiment is illustrated in Figure 1.

Experiment 2

In general, as the level of dietary fat was increased, feed intake and feed:gain decreased linearly ($P < 0.05$.

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Table 4. Exp. 1: Effects of dietary fat composition on growth performance
(least squares means)

Item	Diet, % soy oil				Pooled SEM
	100	66.7	33.3	0	
Weeks 0–2, n = 288					
ADG, kg	0.92	0.94	0.89	0.90	0.02
ADFI, kg[a]	2.49	2.67	2.67	2.73	0.04
Feed:gain[a]	2.75	2.86	3.05	3.07	0.05
Weeks 3–4, n = 288					
ADG, kg	0.92	0.87	0.88	0.97	0.03
ADFI, kg[a]	2.77	3.04	3.07	3.20	0.06
Feed:gain[a]	3.01	3.53	3.54	3.75	0.09
Weeks 5–6, n = 192					
ADG, kg	0.83	0.83	0.78	0.79	0.03
ADFI, kg[a]	3.00	3.15	3.33	3.42	0.06
Feed:gain[a]	3.63	3.95	4.32	4.48	0.17
Weeks 7–8, n = 96					
ADG, kg	0.87	0.99	0.93	0.99	0.06
ADFI, kg[a]	3.09	3.23	3.36	3.73	0.10
Feed:gain[b]	3.59	3.34	3.81	3.91	0.25

[a]Linear effect of diet ($P < 0.0001$).
[b]Linear effect of diet ($P < 0.1$).

Table 6). From d 0 to 42, ADFI and ADG were greater ($P < 0.05$) in barrows than in gilts. However, overall, gilts fed 0% dietary fat were more efficient than gilts fed 2.5% dietary fat, whereas the efficiency of barrows improved linearly with increased dietary fat (sex × dietary fat level interaction; $P < 0.05$). No effects of dietary fat level or type were detected on carcass weight and drip loss (Table 7). A negative quadratic effect ($P < 0.05$) of dietary fat source on fat depth was observed. Significant sex × dietary fat source interactions were observed for fat depth ($P < 0.10$), muscle depth ($P < 0.05$), and lean percentage ($P < 0.05$) (Table 7). For lean percentage of barrows a quadratic effect of dietary fat source was observed. The quadratic responses are of questionable biological significance because the total depth of fat and muscle appears not to differ between sexes. Dietary fat source resulted in no significant differences in lean percentage of gilts.

As the level of tallow in the diet was increased, the monounsaturates, 16:1 and 18:1, increased linearly. However, 16:1 decreased linearly as the percentage of dietary fat in the diet increased. As the level of dietary tallow increased a greater reduction in 18:2 (Figure 2) and iodine value (Table 7) was observed in diets with 5% dietary fat compared to diets with 2.5% dietary fat (dietary fat level × dietary fat source interaction; $P < 0.05$). Diet 5T caused a greater reduction in 18:2 and iodine value than diets 2.5AV, 2.5B, 5AV, and 5B ($P < 0.05$). In contrast, diet 5AV, in which a 100% animal-vegetable blend was supplemented to the diet at 5%, resulted in a significantly higher ($P < 0.05$) 18:2 content and iodine value of carcass fat than diets Cntrl, 2.5B, 2.5T, 5B, and 5T. The linoleic acid content of backfat in relation to daily dietary intake (based on the pen average intake) of linoleic acid is depicted in Figure 3.

Discussion

To reduce the risk of atherosclerosis and coronary heart disease in humans, the American Heart Association has recommended that 30% of dietary energy come from fat with an even distribution of polyunsaturated, monounsaturated, and saturated fatty acids (Neville, 1990). Because the fatty acid profile of carcass lipids in pigs is easily altered, responds to changes in dietary fat composition, and has the potential to be modified to match dietary recommendations for humans, several researchers have measured the change in fatty acid composition following dietary manipulation (Koch et al., 1968; Anderson et al., 1972; Wiseman and Agunbiade, 1998). The majority of these changes appear in the first 25 d but they have not been well quantified (Wood et al., 1994).

To optimize the level and type of fat to be used in a swine diet, it would be beneficial to know how these two factors affect the resulting fatty acid profile and meat quality, and how long the fat source should be fed to achieve the desired results. The data on linoleic acid intake from Exp. 1 and 2, shown in Figure 3, provide a means to determine the amount and level of a fat source to feed depending on the linoleic acid concentration in the final diet and the desired concentration of linoleic acid in the carcass backfat. Anderson et al. (1972) measured the half-life of linolenic acid as an estimate of fatty acid turnover. Their value of 300 d in an 8- to 12-mo-old pig was determined by feeding two barrows a diet containing 20% linseed oil for 2 mo and then measuring the decline in linolenate back to normal tissue levels. In addition, the half-life was 175 d in ether-extractable muscle lipids and 47 d in muscle membrane lipids (Anderson et al., 1972).

Table 5. Exp. 1: Effects of dietary fat composition fed for 4, 6, or 8 wk on carcass characteristics, backfat unsaturated fatty acid content, iodine value, fat firmness, fat melting point, and stick test (least squares means)[a]

Time:	4 wk				6 wk				8 wk				Pooled SEM
Item Diet, % soy oil:	100	66.7	33.3	0	100	66.7	33.3	0	100	66.7	33.3	0	
Live wt, kg[b]	105	108	103	103	114	117	115	114	125	128	128	129	1.5
Carcass wt, kg[b]	77	80	77	76	85	88	87	84	95	96	96	96	1.5
Fat depth, mm[bc]	15.8	17.6	16.0	16.6	19.5	19.8	22.4	19.4	21.8	20.8	22.1	20.4	0.9
Loin depth, mm[bc]	51.4	46.3	50.4	49.5	58.0	58.0	55.4	54.6	56.3	57.2	57.8	57.5	1.4
Lean percentage[b]	55.4	53.7	55.1	54.7	53.9	53.7	51.8	53.6	52.6	53.0	52.3	53.3	0.6
Drip loss, %[c]	3.8	3.4	3.4	3.8	4.9	4.9	5.9	4.3	3.6	3.1	4.0	3.7	0.4
16:1, %[bde]	2.42	2.49	2.40	2.43	2.16	2.28	2.47	2.70	2.44	2.59	2.66	3.21	0.1
18:1, %[bde]	38.7	39.0	39.4	38.9	36.9	38.7	39.2	40.8	38.4	39.6	39.9	42.9	0.4
20:1, %[f]	0.67	0.80	0.80	0.79	0.95	0.83	0.71	0.69	0.81	0.91	0.82	0.67	0.05
Iodine value[be]	81.7	79.3	81.6	82.3	86.1	83.6	78.4	76.2	84.2	80.8	76.7	72.6	1.1
Fat firmness, kg[bce]	93.9	98.2	112.8	114.0	70.1	72.2	67.6	79.9	82.3	77.8	93.8	89.3	6.5
Fat melting point, °C[d]	34.6	34.1	34.2	34.3	34.4	34.7	34.4	34.5	33.6	33.6	33.4	33.6	0.2
Stick test, cm[c]	11.2	10.9	10.9	11.7	11.9	11.7	12.2	12.7	9.1	12.2	10.9	9.4	1.0

[a] Each value is the mean of eight pens of three pigs each.
[b] Linear time effect (P < 0.05).
[c] Quadratic time effect (P < 0.05).
[d] Diet x time interaction (P < 0.05).
[e] Linear diet effect (P < 0.05).
[f] Percentage by weight.

Due to the development of lean genotype pigs since that time, new data are needed regarding how the level of inclusion, fat source, and length of time fed can affect the fatty acid turnover and composition of pork. In other modeling work, a decrease in fat depth of 10 mm was associated with an increase of 4 iodine value units (Barton-Garde, 1984). Similarly, Wood et al. (1978) measured increased 18:2 concentrations in lean, fast-growing lines. Rates of de novo fat synthesis are also reduced in genetically lean pigs compared to pigs with a genetic disposition for fat deposition (Steele et al., 1974). In addition, diet enrichment of specific fatty acids decreased de novo lipogenesis, the reduction depending on fatty acid chain length and degree of unsaturation (Smith et al., 1996). Further, pigs with a reduced capacity for lipogenesis appear to have a greater rate of lipolysis (Standal et al., 1973; Wood et al., 1977). A reduction in adipose tissue accretion has also been observed in porcine somatotropin (pST)-treated pigs, resulting in decreased fat depth over the 10th rib (Lonergan et al., 1992). The effect of pST on backfat depth has been attributed to a reduction in lipogenesis without a concurrent change in fatty acid composition (Dunshea et al., 1992; Lonergan et al., 1992). However, because the depth of the more saturated middle and inner backfat layers was reduced more than the outer layer (Lonergan et al., 1992), the unsaturated fatty acid content of samples containing all three layers could increase proportionally.

More recently, using a modern lean genotype, Wiseman and Agunbiade (1998) determined that the changes in tissue fatty acid concentrations are indeed rapid. They estimated that 60 to 70% of the theoretical capacity for change was reached in the first 2 wk following dietary changes. They noted that the rate and the amount of change that may occur depend on several factors, including initial tissue concentrations. In our study, tissue linoleic acid concentration did not appear to increase during the 3-wk loading period of Exp. 1 (Figure 1). An experiment conducted by Warnants et al. (1999) used the opposite approach. Pigs first consumed a diet containing 2.5% tallow to increase tissue lipid saturation. Then, researchers measured the increasing degree of unsaturation as pigs consumed a diet containing 15% full-fat soybeans (FFS). After 6 wk, the backfat PUFA content of the pigs consuming the FFS was not different from that of pigs fed the FFS for 8 wk, indicating a plateau had been reached. Our results are in agreement and indicate that 6 to 8 wk of feeding a supplemental fat source will significantly alter the backfat fatty acid profile and may improve pork processing characteristics depending on the supplemental fat source.

Our study confirms findings from other laboratories that backfat fatty acid composition reflects dietary fat composition (Seerley et al., 1978; Miller et al., 1990; Madsen et al., 1992). In Exp. 1, fat firmness increased as soy oil was removed from the diet and the proportions of 18:2 decreased but 16:1, 18:0, and 18:1 increased (Table 5). Increasing tallow in the diet (Exp. 2) resulted in similar changes in the carcass fatty acid profile. Piedrafita

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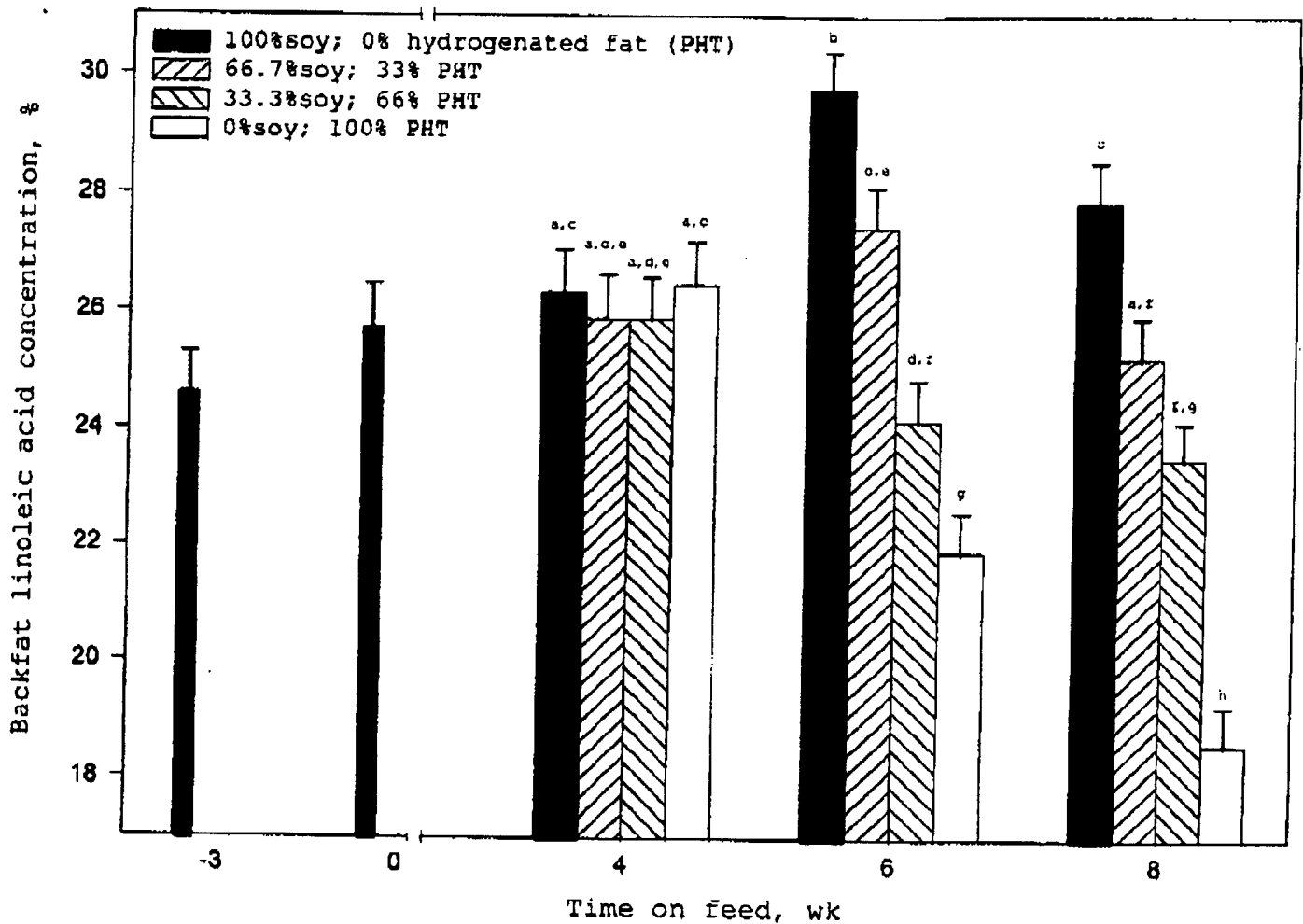
Figure 1. Time course of changes in linoleic acid content of backfat from gilts fed diets varying in fat composition (Exp. 1). Data are least square means (n = 24/treatment). Error bars represent ± SEM. Bars lacking a common letter differ (P < 0.05). Linoleic acid means at 0 and −3 wk (n = 96) are not statistically compared because those means include all animals prior to allocation of treatments. Linear diet effect (P < 0.05). Linear time effect (P < 0.05). Diet × time interaction (P < 0.05). †Percentage by weight.

et al. (2001) noted a positive correlation between fat firmness and 16:0 and 16:1 and a negative correlation with 18:2 and 18:3. They concluded that the degree of fat firmness was correlated to the proportion of total unsaturated fatty acids. In addition, animals with a greater amount of lean also had a greater amount of linoleic acid in backfat (Nürnberg et al., 1998). They observed that other fat parameters were negatively correlated to linoleic acid concentration. This relationship is exaggerated in lean-genotype animals and animals fed unsaturated fat sources, resulting in softer carcass fat and increasing processing difficulty. Our study supports this finding and shows that supplemental dietary fat sources containing lower levels of linoleic acid result in reduced backfat linoleic acid levels (Figure 3). It has been recommended that PUFA levels should not exceed 23% in backfat used for salami manufacture for acceptable processing and product acceptability (Warnants et al., 1998). Furthermore, Houbend and Krol (1980) deter-

mined that pork products produced from pigs consuming diets leading to 30% backfat linoleic acid concentrations were highly susceptible to lipid oxidation.

One approach that may be taken in an effort to improve the tissue lipid saturation is to remove supplemental fat from the diet. When a very low fat diet is fed, de novo fat synthesis produces saturated and monounsaturated fatty acids. Research done by Engel et al. (2001) supports this theory; they found decreasing levels of saturated fats in the longissimus muscles of pigs fed choice white grease or poultry fat regardless of level of inclusion. In addition, linoleic acid concentration in the longissimus muscle was greater in those animals consuming 4 or 6% fat compared to those fed the control diet (P < 0.05). This response was linear with respect to increasing fat level of the diet, but the magnitude of the response was small (< 2%). In Exp. 2 of our work, 5% supplemental tallow resulted in a lower backfat linoleic acid concentration and a lower iodine value compared to the 0% supplemen-

Table 6. Exp. 2: Effects of dietary fat level and type on growth performance (least squares means)

Item[a]	Female (n = 147)							Castrate (n = 147)							Pooled SEM
	Cntrl	2.5AV	2.5B	2.5T	5AV	5B	5T	Cntrl	2.5AV	2.5B	2.5T	5AV	5B	5T	
Days 0–14															
ADG, kg[bcd]	1.08	0.93	0.88	0.98	0.99	0.93	1.00	1.11	1.13	0.93	1.06	1.14	1.18	1.17	0.05
ADFI, kg[de]	2.52	2.62	2.60	2.65	2.36	2.39	2.31	3.15	2.97	2.79	2.88	2.72	2.97	2.93	0.13
Feed:gain[bce]	2.53	2.91	2.78	2.77	2.43	2.65	2.37	2.91	2.71	3.07	2.64	2.46	2.58	2.57	0.11
Days 15–28															
ADG, kg	0.91	0.94	0.92	0.97	0.98	0.93	0.98	1.03	0.97	0.96	0.93	0.94	1.05	0.98	0.04
ADFI, kg[bdef]	3.17	3.12	2.99	3.07	2.90	2.94	2.84	3.78	3.41	3.18	3.23	3.23	3.54	3.31	0.10
Feed:gain[de]	3.56	3.45	3.33	3.33	3.02	3.23	2.93	3.72	3.73	3.42	3.56	3.49	3.46	3.51	0.14
Days 29–42															
ADG, kg[e]	0.98	0.93	1.01	1.01	1.02	1.07	1.00	0.92	1.14	0.88	0.91	1.01	0.91	0.98	0.05
ADFI, kg[de]	3.29	3.25	3.27	3.32	2.96	3.14	3.04	3.63	3.65	3.27	3.30	3.41	3.5	3.27	0.12
Feed:gain[de]	3.52	3.61	3.39	3.36	3.00	3.04	3.11	4.15	3.25	3.84	3.80	3.47	3.45	3.42	0.17
Days 0–42															
ADG, kg[d]	0.97	0.92	0.93	0.94	0.97	0.97	0.94	0.93	1.10	0.90	0.98	1.02	1.05	1.02	0.05
ADFI, kg[de]	3.05	3.08	3.18	3.04	2.81	2.93	2.68	3.31	3.64	3.21	3.14	3.22	3.40	3.21	0.13
Feed:gain[f]	3.17	3.39	3.43	3.32	2.80	3.04	2.89	3.78	3.37	3.57	3.23	3.21	3.29	3.20	0.14

[a]Diet abbreviations are defined by the amount (2.5 = 2.5%; 5 = 5.0%) and source of supplemental fat: AV = animal-vegetable blend; B = animal-vegetable + tallow blend; T = tallow.
[b]Quadratic effect of dietary fat level ($P < 0.05$).
[c]Quadratic effect of dietary fat source ($P < 0.05$).
[d]Sex effect ($P < 0.05$).
[e]Linear effect of dietary fat level ($P < 0.05$).
[f]Sex × dietary fat level interaction ($P < 0.05$).
[g]Sex × dietary fat source interaction ($P < 0.05$).

tal fat control, although the magnitude of the change was small (< 1%). Leszczynski et al. (1992) also fed a diet containing tallow and found levels of 18:2 in bacon similar to that in animals consuming a 0% supplemental fat control diet after 3 and 6 wk.

No significant sex differences in the proportion of fatty acids were noted (Table 7). Others have noted differences in individual fatty acids: gilts had a higher proportion of 16:0, 18:2, and 18:3 than barrows (Piedrafita et al., 2001). However, there was a sex × fat level interaction for 18:1. Barrows fed 2.5 or 5% supplemental fat had a reduced proportion of 18:1. The proportion of 18:1 did not change with varying levels of supplemental fat in gilts. Data from a study comparing boars and gilts suggested that a sex effect on fatty acid composition was independent of varying backfat depths (Wood et al., 1989). The type of supplemental fat had a more predictable effect on backfat depth of gilts than of barrows (Table 7; sex × fat type interaction). Supplemental fats resulted in increased backfat depth in gilts, but not in barrows. It is known that gilts are leaner than barrows at similar slaughter weights (Enser, 1991; Warnants et al., 1998). However, the pattern of fatty acid changes should not be dependent on sex (Warnants et al., 1999).

Dietary fat appears to have a greater effect on bacon than on the loin muscle because the two sites may have different levels of sensitivity to direct incorporation of linoleic and linolenic acid (Leszczynski et al., 1992). This difference in sensitivity resulted in increased concentrations of linoleic acid in belly muscle compared to the longissimus muscle in the same animal (Leszczynski et al., 1992). Camara et al. (1996) measured increased lipo-

genic enzyme activities in backfat compared to the longissimus dorsi muscle, again suggesting that the fat layers that are present in bacon may be more sensitive to dietary changes. In addition, the half-life or turnover rate of fatty acids, specifically linolenate, has been shown to vary from 47 to 300 d, depending on the adipose tissue depot measured (Anderson et al., 1972).

Many studies have noted decreased feed intake and increased gain/feed (G/F) with increasing level of supplemental dietary fat (Bayley and Lewis, 1963; Seerley et al., 1978; Engel et al., 2001). In trial 1, ADFI increased ($P < 0.0001$) with decreasing amounts of soy oil. Even though the balance was provided by hydrogenated fat, the apparent digestibility was low and intake increased to compensate for the reduced caloric density (L. Averette Gatlin, unpublished data). Overall, gain, intake, and feed efficiency were not affected by the source of dietary fat in Exp. 2 ($P > 0.10$).

In conclusion, reduction of dietary PUFA content had the desired effect of lowering the 18:2 content and iodine value of pork fat as expected; however, the magnitude of the reduction (from 26% to 18.6% 18:2 and from 86 to 76 iodine value: Exp. 1) was less than desired. This was likely due to the limited digestibility of the saturated animal fat (L. Averette Gatlin, unpublished data). In Exp. 2, reduction of dietary fat level and the substitution of tallow for animal-vegetable blend fat in the diet had the desired effects of lowering the 18:2 content and iodine value of pork fat as expected. However, the magnitude of the reduction from (21.2% to 17.5% 18:2 and from 78.1 to 73.2 iodine value) again was less than desired. Furthermore, although dietary PUFA content affected

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Table 7. Exp. 2: Effects of dietary fat level and type on carcass characteristics, backfat unsaturated fatty acid content, iodine value and stick test (least squares means)

Item[a]	Female							Castrate							SEM
	Cntrl	2.5AV	2.5B	2.5T	5AV	5B	5T	Cntrl	2.5AV	2.5B	2.5T	5AV	5B	5T	
Carcass wt, kg[b]	90	91	90	92	91	92	92	94	92	92	94	94	95	94	1.4
Fat depth, mm[c]	18.3	21.2	20.3	19.2	19.5	20.5	20.9	24.6	23.2	26.8	23.9	24.6	26.9	23.5	1.1
Loin depth, mm[d]	53.3	52.6	53.2	54.8	54.8	56.9	51.7	48.6	50.9	47.5	53.1	50.7	49.3	53.0	1.7
Lean, %[d]	54.1	52.2	52.8	53.7	53.6	53.2	52.3	49.7	50.8	48.2	50.7	50.0	48.4	50.9	0.8
Drip loss, %	3.37	3.24	2.94	2.82	2.94	3.14	2.85	3.32	2.46	3.04	3.58	2.85	3.08	3.29	0.35
16:1, %[d]	2.96	2.81	2.81	2.88	2.61	2.76	2.96	2.99	2.76	2.75	2.97	2.77	2.80	2.83	0.09
18:1, %[g]	41.1	40.9	42.3	42.2	40.7	41.2	42.8	42.1	40.3	41.0	41.6	40.6	41.8	42.3	0.5
20:1, %	0.48	0.61	0.57	0.63	0.61	0.55	0.53	0.59	0.67	0.66	0.51	0.54	0.57	0.57	0.05
Iodine value[b,h]	71.4	73.4	73.2	71.2	76.0	73.7	70.2	70.5	71.5	71.8	72.5	73.3	71.3	69.9	1.2
Stick test, cm[b]	13.69	13.69	13.16	12.40	13.64	13.74	12.70	15.09	13.46	14.07	13.46	14.50	15.67	14.50	0.84

[a]Diet abbreviations are defined by the amount (2.5 = 2.5%; 5 = 5.0%) and source of supplemental fat. AV = animal-vegetable blend; B = animal-vegetable + tallow blend; T = tallow.
[b]Sex effect (P < 0.05).
[c]Sex × dietary fat source interaction (P < 0.10).
[d]Sex × dietary fat source interaction (P < 0.05).
[e]Linear effect of dietary fat level (P < 0.05).
[f]Linear effect of dietary fat source (P < 0.05).
[g]Sex × dietary fat level interaction (P < 0.05).
[h]Dietary fat level × dietary fat source interaction (P < 0.05).
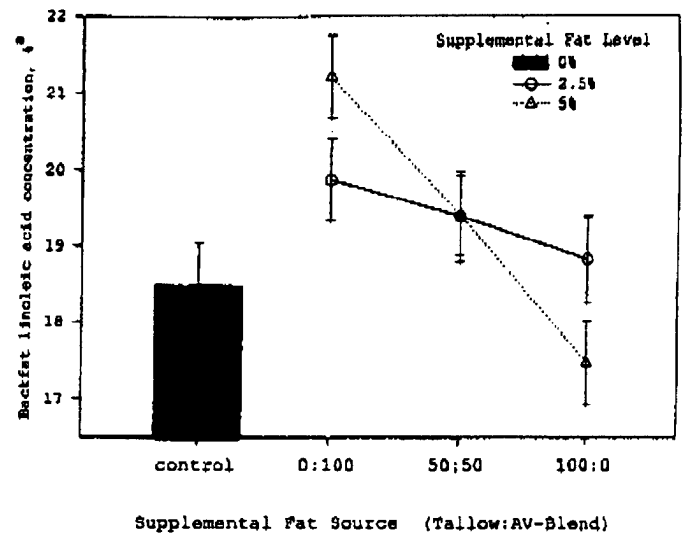
Figure 2. Effects of dietary fat level and composition on backfat linoleic acid concentration (Exp. 2). Data are least squares means (n = 42/treatment). Error bars represent ± SEM. Dietary fat level × dietary fat source interaction (P < 0.05). [a]Percentage by weight.

carcass fatty acid composition, no major effects on measured carcass characteristics (firmness, melting point, and stick test) were detected. This may indicate that these carcass characteristics are not reliable measures of firmness, and ultimately it is not known how they relate to belly processing. An increase in saturation of carcass fat (iodine value down to 68 to 70) would likely
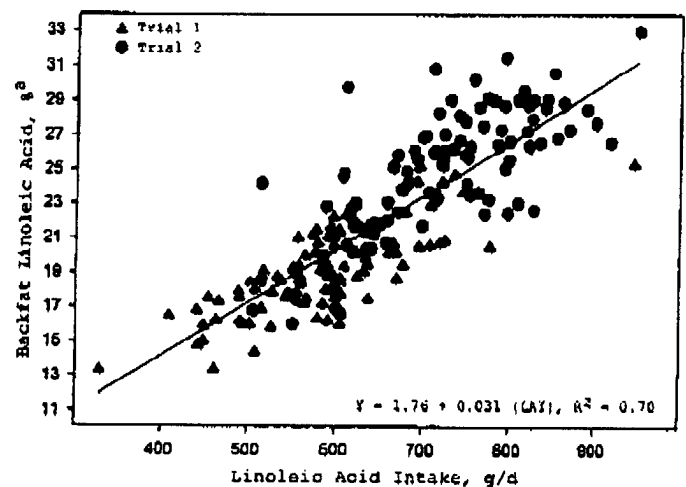
Figure 3. Carcass linoleic acid content (Y) is correlated to the amount of total dietary linoleic acid (LAI). Data points represent actual linoleic acid intake of individual animals (n = 96/trial). Graph represents the regression of daily linoleic acid intake on carcass linoleic acid composition for both trials. Regression for Trial 1: Y = 6.61 + 0.021 (LAI), R^2 = 0.59. Regression for Trial 2: Y = 6.28 + 0.062 (LAI), R^2 = 0.49). [a]Percentage by weight.

result in improved processing and other pork quality attributes. Based on these findings, future research should utilize saturated fat of higher digestibility and should include additional assessment of the effects on other pork-processing characteristics.

Implications

Reducing the linoleic acid content of diets for swine during the 6 to 8 wk prior to slaughter will result in a reduction in linoleic acid and iodine value of pork fat. Further, lowering the amount of linoleic acid is associated with increasing amounts of monounsaturated fatty acids in the carcass. The shift toward a more saturated fatty acid profile as a result of altering the dietary fat level and source will likely improve further processing. The reduction of dietary linoleic acid resulted in a 2 iodine value unit decrease per week, and this rate may likely be increased with supplementation of an even more saturated fat source and(or) lengthening the period in which the fat source is fed, especially in pigs with a backfat depth of < 18 mm.

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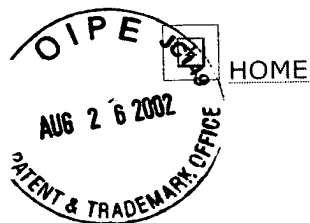
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- Ohio State University (2000), W.P. Weiss & D.J. Wyatt; Effect of Oil Content and Kernel Processing of Corn Silage on Digestibility and Milk Production by Dairy Cows[1] (abstract)●✦
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DuPont Specialty Grains
Poultry Research Trial - AFG6081

Nutritional Value of OPTIMUM® High Oil Corn in Nicholas Tom Turkeys

(November 1991 – March 1992)

Summary

Two types of OPTIMUM® High Oil Corn (OHOC) were evaluated in Nicholas tom turkeys. Control and test feeds were formulated to be isocaloric and isonitrogenous by using OPTIMUM® High Oil Corn ME values that were estimated to be 5.88% and 9.8% greater than typical corn. Weight gains and feed conversion ratios indicated the OPTIMUM® High Oil Corn nutrient composition reflected such performance, and that OPTIMUM® High Oil Corn can be effectively fed to Nicholas toms. Based upon feed ingredient prices at the time in Georgia, the two OPTIMUM® High Oil Corn grains had added values of $0.24 and $0.44 per bushel above the value of typical corn.

Objective

The objective of this study was to evaluate the nutritional value of two types of OPTIMUM® High Oil Corn in Nicholas tom turkeys.

Experimental Procedure

To the knowledge of the author, this was the first reported study that evaluated two types of OPTIMUM® High Oil Corn (6% and 8% oil, separately) in turkeys. A set of five diets (2 starters, 2 growers, and 1 finisher) was formulated using each of the three corn types (2 OHOC and 1 typical corn). Starter 1, starter 2, grower 1, grower 2, and the finisher were fed during 0-3 weeks, 4-6 weeks, 7-9 weeks, 10-12 weeks, and 13-16 weeks, respectively. During each period, the three diets were formulated to be isocaloric and isonitrogenous. Starter feeds were pelleted and crumbled, while grower and finisher feeds were pelleted only. Dietary energy and nutrient levels were similar to those employed in commercial practice and met minimum NRC recommendations.

Poults were started on clean litter at one day of age. Bacitracin (50 g/ton) was used as a growth promoter during the study. The three treatments were randomized in a block design and 18 replicates of 15 poults each were used per treatment.

The two types of OPTIMUM® High Oil Corn evaluated in this study were estimated to contain 5.88% (1620 Kcal/LB) and 9.8% (1680 Kcal/LB) more metabolizable energy than typical corn (1530 Kcal/LB) fed as a control.

The study was conducted at Georgia Poultry Research from November 1991 to March 1992 (GPR192).

Results

Effect on live weight, feed conversion, and mortality.

Treatment	Live Weight (LB)		Feed Conversion		Mortality %	
	Week					
	10	16	0-10	0-16	0-10	0-16
Typical corn (1530 Kcal/LB)	15.3[a]	29.3[a]	2.03[a]	2.66[a]	6.3[a]	11.1[a]
OPTIMUM® High Oil Corn A (1620 Kcal/LB)	15.4[a]	29.5[a]	2.02[a]	2.62[ab]	6.3[a]	12.2[a]
OPTIMUM® High Oil Corn B (1680 Kcal/LB)	15.5[a]	29.5[a]	2.01[a]	2.61[b]	7.8[a]	10.7[a]

Means with different superscripts (P<0.05) are significantly different.

According to the design of this study, if performance of all treatment groups was identical, the assumptions of nutritive value employed in formulation would have been confirmed. Since test birds in this study performed slightly better than controls, it may be concluded that the nutritive (particularly energy) assumptions made at the outset may have slightly underestimated the difference in quality between the control and the OPTIMUM® High Oil Corn.

When feed cost savings and statistically different feed conversions were taken into account, the two OPTIMUM® High Oil Corn grains had average added feed values of $0.24 and $0.44 per bushel. Prices of corn, animal-vegetable fat, and 48% soybean meal used in this study were $6.29, $13.50 and $10 cwt, respectively. The value of OPTIMUM® High Oil Corn will vary depending on the replacement value of added fat and soybean meal and the current price of corn.

This study shows expected performance from commercial Nicholas turkeys can be achieved when OPTIMUM® High Oil Corn is well formulated into practical type diets.

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DuPont Specialty Grains
Pork Research Trial - AFG6065

Effect of OPTIMUM® High Oil Corn on Pig Growth and Carcass Characteristics

Summary

A growth and carcass study was conducted to evaluate the effects of replacing typical corn with OPTIMUM®High Oil Corn. A total of 96 pigs (48 barrows and 48 gilts) were randomly allotted by gender to 24 pens. Pigs were fed from an average body weight of approximately 62 pounds to an average of 245 pounds. Diets were formulated on an equal energy and lysine basis. A three-phase diet sequence was used. Average daily gain, average daily feed intake and feed efficiency were similar between treatments. No significant differences were detected in final pig weight, hot carcass weight, dressing percentage, carcass measurements or estimated lean percentages between pigs fed typical corn and OPTIMUM® High Oil Corn (OHOC). Based on the results of this study, OPTIMUM® High Oil Corn can replace typical corn and supplemental fat.

Objective

Determine the effect of replacing typical corn and choice white grease with OPTIMUM® High Oil Corn.

Experimental Procedure

Ninety-six pigs (48 barrows and 48 gilts) were randomly allotted by gender to 24 pens. Treatments consisted of two corn sources, typical corn and OPTIMUM® High Oil Corn (Table 1).

Table 1. Corn Compositions (100% dry matter basis).		
	OPTIMUM® High Oil Corn	Typical Corn
Crude protein, %	10.10	8.80
Crude fat, %	7.40	3.80
Phosphorus, %	0.27	0.22
Lysine, %	0.31	0.30
Tryptophan, %	0.07	0.10
Threonine, %	0.32	0.35

Pigs were fed a sequence of three diets from an average body weight of approximately 62 pounds to 245 pounds (Table 2). The typical corn/choice white grease components of the feeding program were replaced by OPTIMUM® High Oil Corn. Diets were formulated to contain equal nutrient and energy contents. Analyzed nutrient values of ingredients were used in formulations. Metabolizable energy content of OPTIMUM® Oil Corn was assumed to be 75 kcal/lb more than typical corn based on previous swine ME studies.

Table 2. Composition of diets in three-phase diet sequence (As fed basis).

	Phase 1		Phase 2		Phase 3	
	OHOC	Typical Corn + Fat	OHOC	Typical Corn + Fat	OHOC	Typical Corn + Fat
Moisture, %	12.34	11.63	12.19	11.80	13.21	11.66
Crude Protein, %	19.42	19.53	16.82	17.06	13.83	14.80
Fat, %	5.12	5.06	5.64	5.50	6.21	5.90
Lysine, %	1.13	1.09	.94	.94	.72	.73
Lys:Calorie (g lys:Mcal ME)	3.46	3.4	2.7	2.7	2.1	2.1

Pigs were slaughtered at a commercial facility. Backfat depth, loin depth and estimated carcass lean were determined by Fat-O-Meater. Tenth rib fat depth and longissimus area were measured following a 24-hour chill. Samples of subcutaneous fat from each of the four pigs per pen were collected and pooled for fatty acid analysis.

Results

Average daily gain, average daily feed intake and feed efficiency were similar among treatments.

Table 3. Feed intake, average daily gain and feed efficiency of pigs.

	Treatments		
Item	OPTIMUM® High Oil Corn	Typical Corn + Fat	Coefficient of Variation
Initial weight, lb	61.6	61.9	
Final weight, lb	249.9	245.3	2.8
Daily feed intake, lb	5.26	5.21	6.2
Average daily gain, lb	1.89	1.86	5.2
F/G	2.77	2.80	6.2

No significant differences were detected in final pig weight, hot carcass weight, dressing percentage, carcass measurements or estimated lean percentages between pigs fed typical corn and OPTIMUM® High Oil Corn.

Table 4. Carcass characteristics.

Item	Treatments		Coefficient of Variation
	OPTIMUM® High Oil Corn	Typical Corn +Fat	
Hot carcass weight, lb	185.3	182.8	7.1
Carcass yield, %	74.3	74.5	2.2
Backfat depth, in	1.02	.98	25.5
Loin depth, in	2.12	2.15	11.7
Carcass lean, %	50.01	50.21	7.9
10th rib fat depth, in	1.16	1.15	22.4
10th rib longissimus area, in^2	6.92	6.86	13.4

Fatty acid profiles of back fat were different in pigs fed typical corn versus OPTIMUM® High Oil Corn.

Table 5. Fatty acid profile of subcutaneous fat.

Item	Treatments		Coefficient of Variation
	OPTIMUM® High Oil Corn	Typical Corn + Fat	
Myristic (14:0), %	1.16	1.24	6.3
Palmitic (16:0), %	22.28	23.47	3.4
Palmitoleic (16:1), %	1.78	2.38	30.4
Stearic (18:0), %	12.54	13.20	6.0
Oleic (18:1), %			

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Beef Research Report - AFG7004

Effects of Combinations of Dry Rolled OPTIMUM® High Oil Corn and High Starch Corn on Performance of Finishing Feedlot Steers

(Pioneer Livestock Research Center, Polk City, Iowa, 1998)

Summary

Yearling feedlot steers were fed various combinations of OPTIMUM® High Oil Corn and high starch corn (PIONEER® hybrid 32J55) for 119 days. Steers fed diets containing of their grain as OPTIMUM High Oil Corn tended to gain faster (3.14 pounds per day vs. 3.07 pounds per day) and had better feed efficiency (6.27 pounds of feed dry matter per pound of liveweight gain vs. 6.36 pounds of feed dry matter per pound of liveweight gain) than steers fed high starch corn. However, steers fed mixtures of OPTIMUM High Oil Corn and high starch corn tended to consume more dry matter and had higher gains than those fed either grain alone. The steers with the best performance were those fed 66 percent high starch grain with 34 percent OPTIMUM High Oil Corn grain. No effects of grain type on carcass quality measurements were detected.

Objective

The objective of this study was to determine the feeding value of dry rolled OPTIMUM High Oil Corn when fed in various proportions with a high starch corn on feedlot performance and carcass characteristics of yearling steers.

Experimental Procedure

Eighty (80) Angus and Angus-crossbred steers, each initially weighing approximately 840 pounds, were utilized in a 119-day performance trial. The steers all came from a single source and had similar genetic and nutritional backgrounds. Steers were randomly allotted (16 steers per treatment) to five diets containing various proportions of OPTIMUM High Oil Corn and high starch corn. The five treatments evaluated are outlined in Table 1.

Table 1. Treatments Evaluated					
Ingredient	Treatment	Treatment #2	Treatment #3	Treatment #4	Treatment #5
High Starch Corn, %	100	66	50	34	0
OPTIMUM High Oil Corn, %	0	34	50	66	100

The high starch corn grain utilized in this study was PIONEER brand hybrid 32J55. This hybrid was selected based on its high starch content. Grain from this hybrid typically contains about 3 percentage units more starch than the average of other hybrids. The OPTIMUM High Oil Corn utilized in this study was not isogenic to the conventional hybrid fed. Nutrient analysis for the two grains is shown in Table 2. Both grains were dry rolled utilizing a Ross Kamp Roller Mill to fracture each kernel into three to four pieces. Steers were adapted to their final diet during the initial 28 days of the trial utilizing four transition rations. Final test diets and nutrient compositions are shown in Tables 3 and 4. All test diets were formulated to contain 15 percent roughage (dry matter basis) and supply 275 milligrams of Monensin per head per day. Ration and ingredient samples were taken three times each week; composites (equal weights) from 14-day feeding periods were analyzed for proximate components. All steers were implanted with Revalor® -S at the start of the study. Individual shrunk weights (feed supply being reduced by half and water withheld for 16 hours prior to weighing) were taken on two consecutive days at the start and end of the trial. Full individual weights were taken every 14 days throughout the study. Each animal was fed individually twice daily utilizing Calan® head gates. Performance data collected included: dry matter (DM) intake, weight gain and feed efficiency (feed/gain). Precision Beef Alliance of Atlantic, Iowa, collected hot carcass weights and quality measurements following harvest. Carcass measurements collected included: hot carcass weight, dressing percentage, fat thickness, ribeye area and percent kidney, pelvic and heart (KPH) fat. Quality grade and percent retail product also were called. Cattle performance and carcass data were analyzed by General Linear Model procedure of SAS using least square means. Calculated yield grades and marbling scores were analyzed by Mantel-Haenszel procedures.

Table 2. Chemical Analysis of OPTIMUM High Oil Corn and High Starch Corn (DM Basis)

Nutrient	High Starch Corn	OPTIMUM High Oil Corn
Dry Matter, %	87.53	89.32
Crude Protein, %	9.10	8.89
ADF, %	3.60	3.90
Oil, %	3.56	8.10
Calcium, %	.02	.02
Phosphorus, %	.25	.28
Starch, %	72.73	66.43

Table 3. Final Diets (DM Basis)

Ingredient	Treatment #1	Treatment #2	Treatment #3	Treatment #4	Treatment #5
High Starch Corn, %	80.00	53.30	40.00	26.70	0.00
OPTIMUM High Oil Corn, %	0.00	26.70	40.00	53.30	80.00
Alfalfa Silage, %	7.50	7.50	7.50	7.50	7.50

Alfalfa Hay, %	7.50	7.50	7.50	7.50	7.50
Supplement, %	5.00	5.00	5.00	5.00	5.00

Table 4. Nutrient Analysis of Final Diets (DM Basis)

Nutrient	Treatment #1	Treatment #2	Treatment #3	Treatment #4	Treatment #5
Dry Matter, %	75.80	76.25	76.62	76.37	76.52
Protein, %	14.17	14.51	14.41	13.81	13.82
ADF, %	11.10	11.60	11.77	10.33	11.20
Oil, %	3.53	4.82	5.34	5.69	6.93
Calcium, %	.70	.75	.75	.66	.69
Phosphorus, %	.36	.38	.37	.36	.37

Results

Feedlot Performance. Steer performance results are shown in Table 5. There were no statistical (P>.05) differences between treatments. However, steers fed 100 percent OPTIMUM High Oil Corn tended to gain faster (3.14 pounds per day vs. 3.07 pounds per day) and had better feed efficiency (6.27 pounds of feed dry matter per pound of liveweight gain vs. 6.36 pounds of feed dry matter per pound of liveweight gain) than steers fed 100 percent high starch corn. Steers fed various combinations of OPTIMUM High Oil Corn and high starch corn tended to consume more dry matter and had higher rates of gain than those fed either 100 percent OPTIMUM High Oil Corn or 100 percent high starch corn. The best cattle performance was for steers fed 66 percent high starch corn with 34 percent OPTIMUM High Oil Corn (treatment No. 2). Those steers consumed 5 percent more feed (20.49 pounds per day vs. 19.49 pounds per day), gained 10 percent faster (3.38 pounds per day vs. 3.07 pounds per day) and were 3.3 percent more efficient (6.15 pounds of feed dry matter per pound of liveweight gain vs. 6.36 pounds of feed dry matter per pound of liveweight gain) than steers fed high starch corn alone. Positive associative affects have been noted in several previous feedlot studies from feeding combinations of different grain sources. Most of such positive associative affects have been attributed to improved rumen health and a reduced incidence of sub-clinical acidosis. Feeding supplemental fat in high concentrate finishing diets has been shown to reduce the incidence of acidosis. The OPTIMUM High Oil Corn fed in this study contained more oil but 5.3 percent less starch than the high starch corn. Thus, diets containing a combination of OPTIMUM High Oil Corn and high starch corn would have less starch and thereby should reduce the prevalence of acidosis. These data suggest feeding a combination of OPTIMUM High Oil Corn with high starch corn may improve performance over feeding all the grain as either OPTIMUM High Oil Corn or high starch corn alone.

Table 5. Animal Performance

Item	Treatment #1	Treatment #2	Treatment #3	Treatment #4	Treatment #5

No. Head	16	16	16	16	16
Initial Weight, lb	837	838	837	837	837
Final Weight, lb	1,203	1,240	1,215	1,220	1,210
Dry Matter Intake, lb/d	19.49	20.49	19.87	20.23	19.27
Average Daily Gain, lb	3.07	3.38	3.17	3.22	3.14
Feed/Gain	6.36	6.15	6.35	6.40	6.27

Carcass Characteristics. Carcass data are presented in Table 6. No significant (P>.05) differences were observed between treatments in any carcass trait. Steers receiving the 66 percent high starch corn plus 34 percent OPTIMUM High Oil Corn mixture tended to have heavier hot carcass weights, higher dressing percentages and more subcutaneous fat than steers fed other diets. Research from Idaho indicated the percentage of carcasses graded Choice was 31 percentage units greater for steers fed dry rolled OPTIMUM High Oil Corn than for steers fed typical corn (78 percent of the steers fed OPTIMUM High Oil Corn graded Choice; 47 percent of the steers fed the control corn graded Choice). In this trial, no differences in marbling were detected. More research is needed to examine the effects of OPTIMUM High Oil Corn on marbling scores of finishing beef cattle. Certain genetic strains of cattle may be more responsive to OPTIMUM High Oil Corn in terms of marbling scores.

Table 6. Carcass Characteristics					
Item	Treatment #1	Treatment #2	Treatment #3	Treatment #4	Treatment #5
Hot Carcass Weight, lb	772.6	801.5	778.2	786.6	777.4
Dressing Percent	64.2	64.7	64.10	64.5	64.2
Fat Thickness, in	.45	.58	.42	.52	.43
Ribeye Area, in²	13.24	13.65	13.02	12.88	13.35
KPH, %	2.50	2.31	2.41	2.40	2.30
Yield Grade	2.84	2.66	2.81	3.16	2.74
Called Grade % Choice+	0.00	0.00	0.00	0.00	6.67
% Choice	13.33	0.0	25.00	6.67	6.67
% Choice-	53.33	62.50	50.00	66.67	53.33
% Select+	26.67	31.25	6.25	13.33	20.00
% Select	0.00	0.00	0.00	0.00	0.00
% Select-	6.67	0.0	18.75	13.33	13.33
% Standard	0.00	6.25	0.00	0.00	0.00

Marbling Score*	523	495	531	510	521
* 500 = low Choice					

Conclusion

Steers fed 100 percent OPTIMUM High Oil Corn tended to gain faster (3.14 pounds per day vs. 3.07 pounds per day) and had better feed efficiencies (6.27 pounds of feed dry matter per pound of liveweight gain vs. 6.36 pounds of feed dry matter per pound of liveweight gain) than steers fed 100 percent high starch corn. However, steers fed mixtures of OPTIMUM High Oil Corn and high starch corn tended to consume more dry matter and had higher rates of gain than steers fed either grain type alone. The best overall performance was for steers fed 66 percent high starch corn plus 34 percent OPTIMUM High Oil Corn. This improved performance from the combination may be due to a reduced incidence of subclinical acidosis. These performance differences clearly would provide significant economic benefits to the cattle feeder. Additional research is underway to evaluate various combinations of OPTIMUM High Oil Corn with high starch hybrids to check the repeatability of the results seen in this study. OPTIMUM High Oil Corn did not affect carcass quality grades in this study. More than 60 percent of carcasses in this study graded Choice or better.

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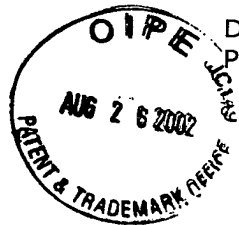© 1999, DuPont Specialty Grains

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Pork Research Report-AFG5002

Effect of OPTIMUM® High Oil Corn or Added Dietary Fat on Pig Growth Performance and Meat Quality

Summary

The effects of substitution of OPTIMUM® High Oil Corn for typical corn and the effects of supplemental fat addition to diets containing OPTIMUM High Oil Corn or typical corn on pig growth performance, carcass characteristics and pork quality were evaluated. Treatments consisted of six dietary regimens in which diets were formulated with typical corn, OPTIMUM High Oil Corn, typical corn plus Fat Source 1, typical corn plus Fat Source 2, OPTIMUM High Oil Corn plus Fat Source 1 or OPTIMUM High Oil Corn plus Fat Source 2. Two hundred seventy (270) gilts that weighed an average of 50 pounds were randomly assigned by weight to 54 pens of five pigs. One of six treatments was randomly assigned to pens within a weight block, resulting in nine replications per treatment. Increasing dietary energy density through the substitution of OPTIMUM High Oil Corn for typical corn or by adding fats to diets formulated with typical corn or OPTIMUM High Oil Corn improved growth performance. In addition, pigs consuming diets containing OPTIMUM High Oil Corn had increased loin-eye depth. This may be due to improved amino acid digestibility of OPTIMUM High Oil Corn. Fatty acid profiles of pork fat were influenced by dietary fatty acid profile. While there was no effect of OPTIMUM High Oil Corn on oxidative stability, taste or shelf life of pork products when compared to typical corn, the two fat sources evaluated differed in their effects on pork quality characteristics. Based on the results of this study, increasing dietary energy density with OPTIMUM High Oil Corn results in improved animal performance when compared to pigs fed diets with typical corn and no added fat. In addition, fat can be added to OPTIMUM High Oil corn to further improve animal performance. There is no effect of OPTIMUM High Oil Corn on pork quality; however, supplemental feed fats may differ in their effect on oxidative stability, shelf life and sensory characteristics of pork.

Objective

The objective of this experiment was to evaluate the effects of substitution of OPTIMUM High Oil Corn or typical corn and the efforts of supplemental fat addition to diets containing typical corn or OPTIMUM High Oil Corn on pig growth performance and on carcass and meat quality.

Experimental Procedure

Two hundred seventy (270) gilts with a weight of 50 pounds were transported to a contract research facility and randomly allotted to pens of five pigs. Treatments were randomly assigned to pens.

Treatments consisted of six corn/fat regimens

1) Typical corn

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2) OPTIMUM High Oil Corn
3) OPTIMUM High Oil Corn plus Fat Source 1
4) OPTIMUM High Oil Corn plus Fat Source 2
5) Typical corn plus Fat Source 1
6) Typical corn plus Fat Source 2

The nutrient compositions of the corn grain used are shown in Table 1. OPTIMUM High Oil Corn contained more oil and less crude protein and essential amino acids when compared to the typical corn. OPTIMUM High Oil Corn will, on average, have greater amino acid density than typical corn; however, the OPTIMUM High Oil Corn and typical corn lots used in this experiment were not from the same genetic background. It appears that background genetic effects had a greater impact on amino acid composition than the high oil corn effect. Actual nutrient compositions were used in diet formulation. OPTIMUM High Oil Corn and typical corn plus Fat Source treatments (Treatments 2, 3, 4) were formulated to be isocaloric.

Table 1. Nutrient Composition of Corn (All values are on a dry matter basis.)

Nutrient, %	Typical Corn	OPTIMUM High Oil Corn
Protein	9.04	7.86
Crude Fat	4.10	6.82
Crude Fiber	2.43	2.46
Ash	1.4	1.2
Calcium	0.012	0.012
Phosphorus	0.29	0.26
ME, kcal/lb[1]	1,773	1,844

Amino Acid, g/100 g		
Tryptophan	0.059	0.059
Lysine	0.297	0.284
Histidine	0.279	0.243
Ammonia	0.212	0.179
Arginine	0.413	0.369
Aspartic Acid	0.552	0.498
Threonine	0.289	0.255
Serine	0.398	0.332
Glutamic Acid	1.440	1.174
Cystine	0.214	0.187
Glycine	0.323	0.296

Alanine	0.620	0.531
Valine	0.395	0.340
Methionine	0.176	0.166
Isoleucine	0.282	0.239
Leucine	0.999	0.821
Tyrosine	0.340	0.288
Phenylalanine	0.338	0.277
Taurine	0.000	0.000
[1]Calculated from Estimate® 3.01		

The fatty acid profiles of the fat sources and the oil in the corn sources are shown in Table 2. The two fat sources were selected because of expected differences in fatty acid profile with Fat Source 1 similar to beef tallow and Fat Source 2 similar to poultry fat. Actual differences in fatty acid profile were smaller than published values. Consistent with previous observations corn oil from OPTIMUM High Oil Corn had a greater percentage of oleic acid and reduced linoleic acid when compared to typical corn oil.

Table 2. Fatty Acid Profile of Fat and Corn Sources

Fatty Acid, %	Fat Source 1	Fat Source 2	Oil in Typical Corn	Oil in OPTIMUM High Oil Corn
Myristic, 14:0	1.38	0.81	0.0	0.0
Myristoleic, 14:1	0.00	0.30	0.0	0.0
Palmitic, 16:0	23.40	23.79	13.9	12.1
Palmitoleic, 16:1	3.26	7.36	0.0	0.0
Stearic, 18:0	12.09	6.04	1.8	1.9
Oleic, 18:1	42.95	43.67	25.4	33.2
Linoleic, 18:2	14.18	15.80	57.7	51.6
Linolenic, 18:3	0.75	0.88	0.9	0.8
Arachidic, 20:0	0.44	0.22	0.2	0.4
Eicosenoic, 20:1	0.95	0.55	0.2	0.2
Iodine Value	70.34	78.39	124.3	120.2

[1] Iodine Value (%16:1 x .95) + (%18:1 x .86) + (%18:2 x 1.732) + (%18:3 x 2.616) + %20:1 x .785) + (%22:1 x .723), AOCS 1993

A three-phase feeding program was used with Phase I diets fed from 50 pounds to 100 pounds, Phase II diets fed from 100 pounds to 175 pounds, and Phase III diets fed from 175 pounds to 240 pounds. The ingredient compositions and calculated

nutrient compositions of individual diets are shown in Tables 3 and 4, respectively. Lysine-to-calorie ratio was constant within a phase across dietary treatments. The OPTIMUM High Oil Corn plus Fat Source 1, OPTIMUM High Oil Corn plus Fat Source 2, typical corn plus Fat Source 1 and typical corn plus Fat Source 2 diets were formulated to be isocaloric. All diets were pelleted. Feed samples were collected and composited for proximate analysis, amino acid composition, fatty acid analysis and iodine value calculation. Pigs were allowed ad libitum access to feed.

Table 3. Composition of Diets

Phase I

Ingredient, %	Treatment					
	Typical Corn	OPTIMUM High Oil Corn	OPTIMUM High Oil Corn + Fat Source 1	OPTIMUM High Oil Corn + Fat Source 2	Typical Corn + Fat Source 1	Typical Corn + Fat Source 2
Typical Corn	69.93	0.00	0.00	0.00	63.68	63.84
OPTIMUM High Oil Corn	0.00	70.28	66.77	66.65	0.00	0.00
Soybean Meal, 48%	27.39	27.04	28.12	28.13	29.65	29.64
Rice Hulls	0.00	0.00	0.43	0.54	0.00	0.00
Fat Source 1	0.00	0.00	2.00	0.00	4.00	0.00
Fat Source 2	0.00	0.00	0.00	2.00	0.00	3.85
Salt	0.250	0.250	0.250	0.250	0.250	0.250
Limestone	0.461	0.232	0.220	0.219	0.429	0.431
Defl. Phosphate	1.398	1.640	1.645	1.646	1.418	1.416
TM/Vitamin Pre-Mix	0.540	0.540	0.545	0.545	0.549	0.549
Antibiotic	0.025	0.025	0.025	0.025	0.025	0.025

Phase II

Ingredient, %	Treatment					
	Typical Corn	OPTIMUM High Oil Corn	OPTIMUM High Oil Corn + Fat Source 1	OPTIMUM High Oil Corn+ Fat Source 2	Typical Corn + Fat Source 1	Typical Corn + Fat Source 2
Corn	75.94	0.00	0.00	0.00	69.70	69.87
OPTIMUM High Oil Corn	0.00	76.48	73.06	72.94	0.00	0.00
Soybean Meal, 48%	21.70	21.15	22.09	22.10	23.77	23.75
Rice Hulls	0.00	0.00	0.475	0.583	0.00	0.00

Fat Source 1	0.00	0.00	2.00	0.00	4.18	0.00
Fat Source 2	0.00	0.00	0.00	2.00	0.00	4.02
Salt	0.250	0.250	0.250	0.250	0.250	0.250
Limestone	0.611	0.360	0.346	0.345	0.574	0.576
Defl. Phosphate	0.954	1.221	1.230	1.231	0.982	0.979
TM/Vitamin Pre- Mix	0.500	0.500	0.500	0.500	0.500	0.500
Choline Chl, 70%	0.019	0.019	0.025	0.025	0.025	0.028
Antibiotic	0.025	0.025	0.025	0.025	0.025	0.025

Phase III						
	Treatment					
Ingredient, %	Typical Corn	OPTIMUM High Oil Corn	OPTIMUM High Oil Corn + Fat Source 1	OPTIMUM High Oil Corn + Fat Source 2	Typical Corn + Fat Source 1	Typical Corn + Fat Source 2
Corn	81.51	0.00	0.00	0.00	75.36	75.54
OPTIMUM High Oil Corn	0.00	82.31	78.97	78.86	0.00	0.00
Soybean Meal, 48%	16.27	15.45	16.26	16.27	18.07	18.06
Rice Hulls	0.00	0.00	0.525	0.633	0.00	0.00
Fat Source 1	0.00	0.00	2.00	0.00	4.35	0.00
Fat Source 2	0.00	0.00	0.00	2.00	0.00	4.19
Salt	0.250	0.250	0.250	0.250	0.250	0.250
Limestone	0.659	0.387	0.371	0.370	0.617	0.619
Defl. Phosphate	0.786	1.077	1.091	1.092	0.821	0.819
TM/Vitamin Pre-Mix	0.500	0.500	0.500	0.500	0.500	0.500
Choline Chl, 70%	0.000	0.000	0.000	0.000	0.008	0.008
Antibiotic	0.025	0.025	0.025	0.025	0.025	0.025

Table 4. Calculated Compositions of Diets by Phase	
Treatment	

	Typical Corn	OPTIMUM High Oil Corn	OPTIMUM High Oil Corn + Fat Source 1	OPTIMUM High Oil Corn + Fat Source 2	Typical Corn + Fat Source 1	Typical Corn + Fat Source 2
Phase _I_						
Protein, %	18.67	19.02	19.25	19.25	19.26	19.27
Fat, %	2.5	4.6	6.4	6.4	6.4	6.4
ME, kcal/lb	1495	1544	1576	1576	1576	1576
Lysine, %	1.02	1.05	1.07	1.07	1.07	1.07
Calcium, %	0.80	0.80	0.80	0.80	0.80	0.80
Phosphorus, %	0.70	0.70	0.70	0.70	0.70	0.70
Phase II						
Protein, %	16.42	16.73	16.90	16.90	16.91	16.92
Fat, %	2.7	4.9	6.6	6.6	6.6	6.6
ME, kcal/lb	1500	1553	1585	1585	1585	1585
Lysine, %	0.86	0.89	0.90	0.90	0.90	0.90
Calcium, %	0.70	0.70	0.70	0.70	0.70	0.70
Phosphorus, %	0.60	0.60	0.60	0.60	0.60	0.60
Phase III						
Protein, %	14.25	14.50	14.61	14.61	14.63	14.63
Fat, %	2.9	5.2	7.0	7.0	7.0	7.0
ME, kcal/lb	1503	1560	1591	1591	1591	1591
Lysine, %	0.70	0.73	0.74	0.74	0.74	0.74
Calcium, %	0.65	0.65	0.65	0.65	0.65	0.65
Phosphorus, %	0.55	0.55	0.55	0.55	0.55	0.55

Individual weights were recorded and feed intakes calculated at the beginning of the experiment and at each diet phase change. Average daily gains and feed efficiencies were adjusted for culled or dead pigs.

When the average weight of a treatment replicate reached approximately 240 pounds, animals were slaughtered. Hot carcass yield, backfat thickness, loin thickness and content were determined. Carcass fat samples were collected for fatty acid analysis and iodine value calculation. For quality evaluation, ham samples were collected from both sides of three animals per replicate.

Measurement of Oxidative Stability. The concentrations of 2-thiobarbeturic acid (TBA) reacting substances as an objective measure of rancidity were determined in fresh ham following storage at 1 degree Celsius or minus 23 degrees Celsius after 0, 6, 12, 18 and 24 days.

Sensory Study. Sensory characteristics of uncured ham were evaluated post-cooking and after storage at 2 degrees Celsius for 0 days or 6 days by a trained panel. Ham was cooked to an internal temperature of 82 degrees Celsius and cooled for 15 minutes prior to serving.

Shelf-life Study. Twenty-four (24) ham samples per treatment were cooked to an internal temperature of 82 degrees Celsius, cooled for six hours and then stored at 1 degree Celsius. Weepage (cumulative fluid loss) and external skin bacteria content were determined at 0, 6, 12, 18 and 24 days. Weepage was measured by draining and weighing the moisture that accumulated in double-sealed bags, while external skin bacteria were determined by bacterial culture techniques utilizing MacConkey and Blood Agar split plates.

Data were analyzed as a complete randomized design using the SAS General Linear Model procedure.

Results and Discussion

Growth performance results are shown in Table 5. Pigs fed the higher energy diets gained weight more rapidly than those fed the typical corn dietary regimen. Efficiency of feed utilization was greatest for the pigs consuming the OPTIMUM High Oil Corn plus fat diets.

Table 5. Overall Growth Performance

	Treatment						
	Typical Corn	OPTIMUM High Oil Corn	OPTIMUM High Oil Corn + Fat Source 1	OPTIMUM High Oil Corn + Fat Source 2	Typical Corn + Fat Source 1	Typical Corn + Fat Source 2	Carcass Value
Initial Weight, lbs	49.84	49.82	49.74	49.74	49.84	49.77	1.55
Ending Weight, lbs	238.6^c	245.4^{bc}	254.9^{ab}	256.6^a	248.6^b	251.8^{ab}	3.36
ADG, lbs	1.70^c	1.76^{bc}	1.85^{ab}	1.86^a	1.79^b	1.82^{ab}	4.18
Feed:Gain	3.40^d	3.35^{bcd}	3.28^{ab}	3.26^a	3.35^{bcd}	3.31^{abc}	2.28
Mortality, %	4.44^a	0.00^b	0.00^b	0.00^b	0.00^b	4.44^a	

[1]Means within a row lacking a common superscript differ ($P \leq 0.05$)

Carcass characteristics are found in Table 6. Backfat thickness was greatest for pigs fed the typical corn plus Fat Source 1 diets. Loin-eye thickness was greatest for the pigs fed the OPTIMUM High Oil Corn dietary regimens. Overall, pigs fed the OPTIMUM High Oil Corn dietary regimens were leaner than pigs fed the typical corn treatments. This may be due to greater amino acid digestibility of OPTIMUM High Oil Corn. Although improved digestibility of amino acids in OPTIMUM High Oil Corn has been demonstrated in chick studies, digestibilites of amino acids in OPTIMUM High Oil Corn and typical corn were assumed to be the same for diet formulation in this experiment.

Table 6. Carcass Characteristics

Criteria		Treatment						
	Typical Corn	OPTIMUM High Oil Corn	OPTIMUM High Oil Corn + Fat Source 1	OPTIMUM High Oil Corn + Fat Source 2	Typical Corn + Fat Source 1	Typical Corn + Fat Source 2	Carcass Value
Backfat Thickness, in	0.88^d	0.89^d	0.96^{abc}	0.89^d	1.00^a	0.94^{bc}	5.61
Loineye Thickness, mm	44.78^d	47.82^{bc}	47.96^{bc}	51.54^a	45.12^{cd}	45.44^{cd}	6.98
Lean Cuts, %	57.09^{abcd}	59.88^{abc}	56.17^{cd}	60.72^a	54.37^d	56.71^{bcd}	6.97
Yield, %	71.02^d	73.34^{cd}	74.40^{bcd}	79.82^a	72.15^{cd}	76.54^{abc}	6.53

[1]Means within a row lacking a common superscript differ (P≤0.05)

Fatty acid profiles of backfat and belly fat are shown in Tables 7 and 8, respectively. As documented in many other experiments, fatty acid profiles of pork fat reflected the fatty acid profile of the dietary regimen fed.

Table7. Backfat Fatty Acid Composition[1]

Fatty Acid %		Treatment						
	Typical Corn	OPTIMUM High Oil Corn	OPTIMUM High Oil Corn + Fat Source 1	OPTIMUM High Oil Corn + Fat Source 2	Typical Corn + Fat Source	Typical Corn + Fat Source 1	Coefficient of Variation Source 2
Palmitic	21.3^a	21.0^a	20.2^{bc}	20.7^{ab}	19.9^{cd}	21.4^a	3.2
Palmitoleic	2.43^{de}	2.30^e	2.54^d	2.59^{cd}	2.96^{ab}	3.03^a	6.3
Stearic	11.3^a	10.8^{ab}	9.75^{cde}	10.1^{bc}	9.11^{de}	9.91^{cd}	10.1
Oleic	44.1^a	41.6^b	42.9^{ab}	43.6^a	43.9^a	43.3^a	3.3
Linoleic	16.2^{cd}	19.7^a	20.1^a	18.5^{ab}	19.5^{ab}	17.6^{bc}	5.1
Linolenic	0.70^c	0.72^c	0.77^{abc}	0.71^c	0.86^a	0.82^{ab}	5.9
Total FA	98.56^{ab}	98.70^a	98.68^a	98.72^a	98.62^{ab}	98.77^a	0.14
UFA	64.56^f	65.38^{ef}	67.26^{bcd}	66.42^{cde}	68.11^b	65.91^{def}	2.4
SFA	33.99^a	33.33^{ab}	31.40^{cde}	32.28^{bcd}	30.48^e	32.86^{abc}	5.1
Iodine Value	71.0^c	74.8^{ab}	76.8^a	74.7^{ab}	77.3^a	73.7^{bc}	2.4

[1]Means within a row lacking a common superscript differ (P≤0.05)

Table 8. Pork Belly Fatty Acid Composition[1]

Fatty Acid %	Typical Corn	OPTIMUM High Oil Corn	OPTIMUM High Oil Corn + Fat Source 1	OPTIMUM High Oil Corn + Fat Source 2	Typical Corn + Fat Source 1	Typical Corn + Fat Source 2	Coefficient of Variation
				Treatment			
Palmitic	20.6[a]	19.7[b]	19.0[c]	20.3[ab]	20.4[a]	20.2[ab]	6.3
Palmitoleic	2.75[c]	2.65[d]	2.65[c]	2.72[c]	3.06[b]	3.37[a]	9.9
Stearic	9.79[cd]	9.03[cd]	8.76[d]	9.09[bcd]	9.46[abc]	8.96[cd]	12.7
Oleic	45.9[ab]	43.1[d]	44.8[cd]	45.2[abc]	45.0[ab]	45.2[abc]	4.1
Linoleic	15.9[d]	20.9[a]	20.2[a]	18.7[b]	17.4[c]	17.3[c]	7.7
Linolenic	0.71[de]	0.79[bc]	0.76[bcd]	0.66[e]	0.75[cd]	0.87[a]	12.0
Total FA	98.39[c]	98.63[b]	98.63[b]	99.04[a]	98.47[c]	98.67[b]	0.29
UFA	66.43[c]	68.42[ab]	69.42[a]	68.20[ab]	67.05[bc]	67.86[bc]	7.8
SFA	31.96[a]	30.21[bc]	29.21[c]	30.84[ab]	31.42[ab]	30.82[cd]	3.4
Iodine Value	72.4[f]	78.6[a]	78.8[a]	76.3[bcd]	74.4[def]	75.2[cde]	3.8

[1]Means within a row lacking a common superscript differ (P≤0.05)

Results of the oxidative stability evaluation of ham are shown in Table 9. The TBA values of the ham stored at 1 degree Celsius from pigs fed the typical corn plus Fat Source 1 dietary regimen consistently were greater than ham from the other treatment groups regardless of storage conditions. This would not be predicted from the fatty acid profile of Fat Source 1. Fat Source 1 was more unsaturated (higher IV value) than Fat Source 2. Therefore, oxidative stability of pork from pigs fed Fat Source 2 would be predicted to be less. This observation suggests factors other than fatty acid profile may affect the oxidative stability of pork products.

Table 9. Evaluation of Oxidative Stability of Uncured Ham – TBA Concentration, mg/kg[1]

	Typical Corn	OPTIMUM High Oil Corn	OPTIMUM High Oil Corn + Fat Source 1	OPTIMUM High Oil Corn + Fat Source 2	Typical Corn + Fat Source 1	Typical Corn + Fat Source 2	Coefficient of Variation
				Treatment			
Days Storage at 1°C							

0	0.42	0.41	0.41	0.42	0.43	0.42	5.48
6	1.23[bc]	1.19[c]	1.24[abc]	1.21[c]	1.31[a]	1.25[abc]	6.25
12	1.63[c]	1.62[c]	1.71[bc]	1.69[bc]	1.81[a]	1.74[ab]	6.55
18	2.36[abc]	2.29[bc]	2.38[abc]	2.31[bc]	2.47[a]	2.41[abc]	6.71
24	3.42[cd]	3.40[cd]	3.56[abc]	3.44[bcd]	3.69[a]	3.57[abc]	5.82
Days Storage at -23°C							
6	0.10	0.11	0.10	0.12	0.12	0.13	35.12
12	0.18	0.16	0.16	0.16	0.19	0.19	37.18
18	0.35	0.31	0.32	0.30	0.38	0.35	34.47
24	0.40	0.42	0.44	0.43	0.47	0.46	23.06
30	0.65	0.61	0.67	0.61	0.74	0.71	24.31
60	0.70[c]	0.73[abc]	0.73[abc]	0.70[bc]	0.77[a]	0.76[ab]	8.75
90	1.15	1.16	1.15	1.12	1.23	1.19	9.15
120	1.48[b]	1.59[ab]	1.54[ab]	1.53[ab]	1.64[a]	1.61[ab]	10.82

[1]Means within a row lacking a common superscript differ ($P \leq 0.05$).

The results of the sensory and shelf-life evaluation of ham are found in Table 10. The trained sensory panel used a scoring system that ranged from 1 (very good) to 5 (very poor). Sensory scores were highest for the added fat diets with the scores for the ham from the pigs fed the typical corn plus Fat Source 1 consistently higher than other treatments. Statistically significant differences were observed in water loss percent and bacterial counts, but these differences are likely not practically important.

Table 10. Sensory and Shelf-life Characteristics of Ham[1]

	Treatment						
	Typical Corn	OPTIMUM High Oil Corn	OPTIMUM High Oil Corn + Fat Source 1	OPTIMUM High Oil Corn + Fat Source 2	Typical Corn + Fat Source 1	Typical Corn + Fat Source 2	Coefficient of Variation
Sensory Study[2]							
Day 0	2.67[d]	2.80[cd]	3.02[ab]	2.85[c]	3.12[a]	3.08[ab]	5.47
Day 6	3.62[e]	3.86[cd]	4.18[ab]	4.00[bc]	4.22[a]	4.08[ab]	5.31
Shelf-life Study Water							

Loss, %							
6 Days	1.42[bc]	1.41[bc]	1.47[ab]	1.38[c]	1.53[a]	1.44[bc]	5.28
12 Days	2.84[bcd]	2.78[cd]	2.96[ab]	2.76[d]	3.00[a]	2.82[bcd]	5.71
18 Days	3.07[a]	2.93[abc]	2.97[ab]	2.85[bc]	3.05[a]	2.90[abc]	6.40
24 Days	4.31[a]	4.27[ab]	4.24[abc]	4.08[bc]	4.27[ab]	4.17[abc]	5.40
Shelf-life Study Bacteria (#/mL)							
0 Days	12.0	12.3	12.4	12.0	12.2	12.5	5.36
6 Days	41.3[c]	38.2[d]	51.4[a]	47.8[b]	51.2[a]	47.1[b]	4.99
12 Days	125.0[cd]	120.8[d]	131.5[b]	124.3[cd]	137.3[a]	133.4[ab]	4.40
18 Days	218.1[bc]	214.1[c]	227.2[ab]	208.4[c]	232.9[a]	217.7[bc]	5.20
24 Days	423.0	421.2	430.9	435.3	436.7	431.4	5.49

[1]Means within a row lacking a common superscript differ ($P \leq 0.05$).

[2]Taste Panel Score: 1 = Very Good, 2 = Good, 3 = Average, 4 = Poor, 5 = Very Poor.

Conclusion

Based on the results of this trial, increasing dietary energy density with OPTIMUM High Oil Corn results in improved animal performance when compared to pigs fed diets with typical corn and no added fat. In addition, fat can be added to OPTIMUM High Oil corn to further improve animal performance. Use of OPTIMUM High Oil Corn improved loin-eye depth, likely due to increased amino acid density, and altered fatty acid profile of pork fat, but had no effect on oxidative stability, taste or shelf life of pork products when compared to typical corn; whereas the two feed fat sources differed in their effects on oxidative stability, shelf life and sensory characteristics.

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Influence of Dietary Fat on Carcass Fat Quality in Pigs. A Review

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Danish experiments with growing pigs from the last 40 years are presented to enlighten some of the problems connected with carcass fat quality. In the experiments a variety of feeds have been used, supplying varying amounts of fat differing greatly in fatty acid composition. Generally, when *de novo* fatty acid synthesis, resulting in saturated and monounsaturated fatty acids, is predominant, the back fat will be very firm, while the deposition of dietary polyunsaturated fatty acids will produce soft back-fat. The relationship between the amount and composition of dietary fat and the content and profile of intramuscular fat seems complicated. Oats, rapeseed, sunflower seed, animal fat and vegetable oil should only be included in limited amounts in the diet to avoid high occurrence of unacceptable soft backfat and rancidity of the carcass. The iodine value (IV) of backfat is shown to be related to the iodine value product (IVP) of the dietary fat through the following equation: $IV = 47.1 + 0.14 \times IVP/$day ($R^2 = 0.86$).

Introduction

It is well known that the amount and fatty acid composition of the diet influences carcass fat quality in pigs. From a human nutritional point of view, a ratio of polyunsaturated to saturated fatty acids of at least 0.5 in the diet is recommended (Levnedsmiddelstyrelsen, 1986). For the carcass fat in pigs, such a ratio would increase the iodine value (IV, indicating softer backfat) and decrease storage stability. As fat, however, is also important for the palatability of the meat, recent investigations focus on the intramuscular fat content and the fatty acid composition of skeletal muscle membranes. When analyzing dietary influence on carcass fat quality in pigs, it is necessary to take into account other factors, such as breed, sex, management, feeding level, environment, slaughter weight and possible interactions between these factors.

The importance of nutritional factors in regulating fat quality in lean pigs was discussed in a workshop in a CEC Program (1983) and recently at the EAAP Congress (1991). The present paper will be limited to Danish experiments over the last 40 years concerning the influence of the amount and fatty acid composition of dietary fat on the fatty acid profile of deposited fat and the quality of the pig carcass.

The references are mainly recent ones. Reviews of older literature are given by Madsen (1955) and Christensen (1962; 1969).

Materials and methods

The randomized complete block design has usually been used. In most experiments the pigs were Danish Landrace or crossbred (Landrace × Yorkshire), penned individually from 20 kg until slaughtering at 90 kg live weight. Live weight and feed consumption were registered each fortnight. They were fed twice daily according to a restricted regime, and received water ad libitum.

The contents of crude protein, crude fat, fibre, nitrogen-free extracts and ash in the feeds were determined monthly, and fatty acids and IV 2 or 3 times during each experiment according to standard procedures (Jakobsen & Weidner, 1973).

The IV is a measure of the unsaturation of the fat and is defined as the amount of iodine (in g) bound by 100 g fat. Christensen (1962) proposed the IVP (IV = iodine value, P = product) as a guideline for maximum levels of specific fats in pig diets.

* Neé Christensen.

The IVP is calculated as follows:

IVP = percentage of dietary fat × iodine value × 0.1.

At slaughter the lean meat content was measured, together with a number of carcass quality characters including fatty acid composition and IV of backfat. Furthermore, intramuscular fat in the loin was measured. The chemical analyses were performed at the Central Laboratory, Research Centre Foulum and at the Danish Meat Research Centre, Roskilde. Details of the experimental procedures are to be found in the individual publications cited.

Results and discussion

Fatty acid composition of dietary fat

Table 1 shows the fat content and the fatty acid profile of feed components used in the experiments. Fatty acids only present in small amounts are not given here, but may be found in the publications cited. Coconut fat and palm oil are characterized by a high content of C12:0 (50 and 40%, respectively), while fat from cereal grains and seeds has a relative high proportion of C18:2. Fish oil has a relatively high content of unsaturated fatty acids above C20. Madsen et al. (1991b) used one type of fish meal containing 11% fat, of which the sum of C20:1, C22:1, and C22:6 constituted 40%. Moreover, fish oil and linseed oil are well known for their high content of n−3 fatty acids.

Fat deposition in pigs

Adipose tissue in the carcass is located mainly subcutaneously, less intermuscularly, and very little intramuscularly. The fat deposition is low at birth but increases rapidly as the pigs mature.

Table 2. The effect of adding skimmed milk to a diet based on barley and water on daily gain and carcass quality in pigs (Madsen et al. 1970)

Barley and water	+	+
Skimmed milk	+	−
Daily gain, g (20–90 kg)	722	284
Lean meat, %	60.0	45.6
Fat in carcass, %	29.3	43.4
Fat in loin, %	2.1	5.0

In the weight range 20–90 kg the dietary fat intake for Danish pigs is approximately 4 kg, but the carcass may contain more than 15 kg fat. Hence at least 11 kg fat has been synthesized *de novo* from dietary carbohydrates and protein. Fat deposition is the difference between synthesis and mobilisation and depends upon the energy intake and intake of essential nutrients. As shown in Table 2, the intake of protein supplement (skimmed milk) highly influences fat deposition in pigs and hence the proportion of lean to fat in the carcass.

In the pig, lipid synthesis primarily occurs in adipose tissue and glucose is the major precursor (Christensen and Goel, 1972). When the diet contains increasing amounts of fat, synthesis by the pig itself is decreased and more dietary fatty acids are deposited in adipose tissue (Jakobsen & Thorbek, 1991).

The replacement of energy from carbohydrates by different fat sources is possible to a large extent. Nørby et al. (1967) kept 8 month old boars for 13 months on diets where 10, 20 or 40% of the energy originated from lard or butter. Similarly, Mortensen & Bejerholm (1986) replaced 30% of dietary

Table 1. Fat content, fatty acid composition and iodine value (IV) of experimental feeds

Feeds	Crude fat, %	C14:0	C16:0	C18:0	C18:1	C18:2	C18:3	IV
Barley	3.5	0.2	19.8	0.7	10.4	44.2	4.5	129
Oats, conventional	5.8	0.2	14.7	1.0	27.7	35.2	1.6	113
Oats, naked	11.0	0.2	13.8	0.9	36.4	34.7	1.0	108
Soybean meal	3.1	0.4	18.3	4.2	15.9	51.8	6.8	135
Peas	2.3	0.2	12.6	2.2	13.9	40.3	6.8	137
Animal fat	*	1.8	23.6	13.3	38.8	6.0	0.5	57
Soya oil	*	−	10.0	2.0	29.0	51.0	7.0	140
Rapeseed	41.1	0.1	4.7	1.6	50.2	21.8	9.1	116
Sunflower seed	31.2	0.1	7.0	6.3	22.2	61.6	0.4	132
Linseed oil	*	0.1	6.6	4.9	20.5	14.6	51.9	182
Palm oil	*	12.0	8.3	2.2	23.6	4.0	0.1	29
Coconut fat	*	−	9.0	5.0	8.0	3.0	−	10
Corn oil	*	0.1	10.4	1.6	30.7	54.6	1.7	127

* Approximately 100.

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net energy (NE) by fat in the growth period 20–90 kg without affecting performance.

Like other mammals, pigs are unable to synthesize the essential fatty acids linoleic ($C18:2n-6$) and linolenic ($C18:3n-3$). These fatty acids must therefore be supplied in the diet. From these parent fatty acids other essential fatty acids belonging to the $n-6$ and $n-3$ family, respectively, may be synthesized in the organism by desaturation and chain elongation reactions (Christensen, 1985).

The requirement for dietary linoleic acid for normal growth rate, feed efficiency, nitrogen and energy metabolism is only 0.26% of metabolizable energy (ME) according to Christensen (1985). Further experiments have shown that the dietary requirement for linoleic acid depends on the age at weaning, the composition of the diet and the response parameter implied, and that the requirement to maintain normal physiological and biochemical functions is not more than 1% of dietary energy (Jakobsen, 1990). As is evident from Table 1, diets based on grain and a protein source poor in fat (e.g. soybean meal) will cover the requirement for linoleic acid, whereas alternative feed ingredients poor in fat (e.g. cassava) may not provide a sufficient quantity of linoleic acid. The dietary requirement for linolenic acid has not yet been established in pigs.

The main fatty acids in adipose tissue of pigs are the long-chain fatty acids C16:0, C18:0 and C18:1, which are synthesized in the tissue itself. The medium-chain fatty acids C12:0 and C14:0 are deposited in depot fat, if present in the feed, but only to a limited extent (Christensen, 1962; 1969). This shows that some selection of dietary fatty acids is taking place, possibly to regulate the fluidity of the fat depots. Linoleic and linolenic acids are also found in fat depots, if fed to the pigs, whereas arachidonic acid ($C20:4n-6$) and other C20 and C22 unsaturated fatty acids of the $n-6$ or $n-3$ family are present in such small concentrations that they are not detectable by normal gas–liquid chromatography procedures. Table 3 shows the fatty acid composition

and the IV of some fat depots in pigs fed a traditional barley–soybean meal diet during the growth period (Madsen et al., 1990a). It is obvious that the fatty acid composition of the fat depots is also dependent on the latter's position in the body, the outer backfat layer being more unsaturated than the inner one. This may partly explain the increase in C18:2 with decreasing backfat thickness, resulting in softer backfat, which is found in the modern lean type of pig.

Dietary influence on the fatty acid pattern in backfat

As more unsaturated fatty acids are included in the feed, the backfat becomes softer, and other undesirable quality characteristics mainly caused by oxidation, such as reduced storage stability, rancidity, off-flavours and discolouring of the carcass fat, are also encountered. The risk of oxidation is enhanced when producing bacon, because both brine and smoke contain oxidative components. The trend in human nutrition is towards a higher intake of polyunsaturated fatty acids, notably $n-3$ fatty acids, which are abundant in fish oil, but unfortunately these fatty acids will render the fat depots soft and oily, with a fishy taste. The following experiments show the possibility of changing the fatty acid composition of the fat depots and thereby the quality of the fat and meat products by changing the amount of fat in the feed and the fatty acid composition of the dietary fat.

Several experiments have shown that the saturated fatty acids (C12:0–C18:0) have a positive, while the monounsaturated (C16:1, C18:1) and notably the polyunsaturated fatty acids (C18:2, C18:3) have a negative influence on the firmness and cohesiveness of the carcass fat tissue.

Christensen (1963) replaced 30% of the dietary energy in a control diet with either coconut fat or soya oil. He found that only small amounts of C12:0 and C14:0 from coconut fat were retained in the backfat, while large amounts of C18:2 and C18:3 were retained from the soya oil. The control group had an IV of 47 in the backfat compared with 35 in the coconut fat group and 97 in the soya oil group. While coconut fat resulted in a very firm consistency, the soya oil gave very soft backfat.

Madsen et al. (1977) reported that pigs on high animal-fat diets had very soft backfat compared to pigs on hydrogenated fat, which gave hard, snowy backfat. Colour, taste and storage stability of the bacon were also reduced by feeding animal fat.

Inclusion of 30% linseed oil in the diet, with a high proportion of C18:3, caused yellow fat and a very soft carcass even on chilling (Christensen, 1969). Table 4 shows the fatty acid composition of

Table 3. Fatty acid composition and iodine value (IV) (in g/100 g DM) of leaf fat and backfat in pigs fed a barley–soybean meal diet during the growth period (Madsen et al. 1990a)

Fatty acid	Leaf fat	Inner backfat	Outer backfat
C16:0	26.1	25.5	23.8
C18:0	17.3	14.7	12.0
C18:1	30.8	38.0	39.3
C18:2	8.4	7.5	8.5
C18:3	0.6	0.7	0.8
IV	50.7	51.9	55.9

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Table 4. The influence of the dietary fat source on the fatty acid composition and iodine value (IV) of backfat[a] (Christensen, 1963; 1969)

Fatty acid	Fat free[b]	Barley+ soybean meal	Coconut fat[c]	Soya oil[c]	Linseed oil[c]
C12:0	0.1	0.1	5.3	–	Trace
C14:0	1.4	1.1	15.8	2.0	1.0
C16:0	15.9	21.1	30.5	16.2	14.1
C16:1	6.5	3.1	ND[d]	ND	1.5
C18:0	5.6	15.0	11.5	11.3	10.9
C18:1	63.4	48.9	32.6	29.3	33.2
C18:2	8.1	9.3	4.2	38.6	13.2
C18:3	–	3.4	ND	2.8	26.1
IV	77.8	59.9	42.8	100.0	105

[a] The pigs were fed from 20 to 90 kg LW on barley–soybean meal, vitamins and minerals according to scale.

[b] Basal diet consisted of 85% sucrose, 10% tapioca meal, 5% potato starch. Casein was used as protein source. 1% sunflower oil was added as a source of linoleic acid.

[c] 30% of dietary energy substituting barley.

[d] Not detected.

Table 5. Fatty acid composition and iodine value (IV) of backfat in relation to dietary iodine value product (IVP) (Madsen et al. 1990b)

Oats, % of grain	0	33	67	100
IVP	37	53	68	84
C16:0	26.7	26.0	25.3	24.2
C18:0	16.4	16.3	16.7	15.5
C18:1	41.8	41.2	40.2	40.2
C18:2	7.7	9.2	11.1	13.3
C18:3	0.7	0.7	0.7	0.7
IV	58.4	60.9	63.2	67.4

Rapeseed, %	0	4	8	12
IVP	37	54	72	88
C16:0	26.5	25.1	23.7	22.5
C18:0	15.0	14.2	13.5	12.5
C18:1	42.4	42.3	42.6	43.2
C18:2	8.1	9.9	11.6	12.9
C18:3	0.9	1.5	2.2	2.8
IV	61.0	66.2	71.3	75.9

Sunflower seed, %	0	4	8	12
IVP	37	52	67	82
C16:0	25.5	23.8	22.3	20.4
C18:0	15.3	14.3	13.5	12.5
C18:1	41.9	39.2	36.5	35.3
C18:2	8.1	14.6	19.7	23.8
C18:3	0.7	0.7	0.7	0.7
IV	61.1	70.5	76.8	83.5

back fat from pigs fed 30% coconut fat, soya oil or linseed oil in their diets compared to a virtually fat-free and a traditional barley–soybean meal diet.

Barton-Gade (1987) examined the fat quality in boars, castrates and gilts, and found that IV above 70 can be used as an indicator of soft fat. The iodine value was highest in boars, mainly due to a higher linoleic acid content.

Madsen et al. (1990b) replaced a barley–soybean meal diet partly by alternative feeds such as oats, rapeseed and sunflower seeds. The results shown in Table 5 clearly demonstrate the influence on fatty acid composition of the backfat.

Dietary IVP varied from 37 to 88. The ratio of dietary unsaturated to saturated fatty acids ranged from 1.2 to 1.8 and polyunsaturated to saturated fatty acids from 0.2 to 0.7. The IV of the backfat was similarly influenced and varied from 58 to 84. Furthermore, when sunflower seed was increased from 0 to 12% in the feed, C20:2 in backfat increased from 0.5 to 1.2%. Based on these and earlier results, the following equation between IV in backfat and dietary IVP was calculated (Fig. 1):

$$IV = 47.1 + 0.14 \times IVP/day \quad (R^2 = 0.86)$$

Østerballe et al. (1990) supplemented a barley–soybean meal diet with 6% fat of varying fatty acid composition. Thus, 15 and 31% of C18:2 were combined with either 1.5, 3.7 or 6.0% of C18:3. As shown in Table 6, increasing amounts of dietary C18:2 and C18:3 increased the concentrations of C18:2 and C18:3 in the back fat. Consequently, the ratio of polyunsaturated to saturated fatty acids

increased from 0.2 to 0.6, and IV increased from 55 to 78.

Linolenic acid is mainly present in fish oil and linseed oil, which are not used in Danish diets for growing pigs. Under normal feeding conditions C18:2 is responsible for increased IV of the backfat. As the thickness of backfat has been decreasing over the years, but the intake of linoleic acid has been unchanged or even increased, it follows that the relative concentration of C18:2 in deposited fat
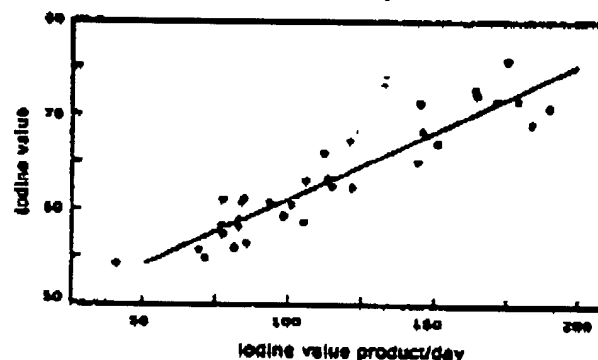

Fig. 1. Iodine value (IV) of backfat in relation to dietary daily intake of iodine value product (IVP).

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Table 8. Fatty acid composition and iodine value (IV) of backfat in relation to dietary intake of C18:2, C18:3 and iodine value product (IVP) (Østerballe et al. 1990)

C18:2	15	15	15	31	31	31
C18:3	1.4	3.7	5.9	1.6	3.8	6.0
IVP	52	58	64	81	87	93
C16:0	25.6	24.9	24.9	23.4	23.0	22.3
C18:0	12.2	12.3	12.6	12.0	11.7	11.9
C18:1	39.1	38.2	38.0	36.0	35.1	35.3
C18:2	7.4	8.0	8.3	16.8	17.7	17.7
C18:3	0.6	1.6	2.7	0.8	1.8	3.0
IV	54.9	59.0	62.6	70.0	74.4	78.2

has increased. Therefore, carcass fat is softer in the modern type of pig than in older ones.

Limits to certain feeds, fats and oil

As already mentioned, an IV of more than 70 is unacceptable owing to the soft backfat and reduced storage stability. It is therefore necessary to limit the amount of certain feeds. According to our results, the diet should not contain more than 4% rapeseed or sunflower seed. Only 67% of barley should be replaced by conventional oats, or 50% by naked oats. Fats and oil must be limited to a different extent. When IVP of the diet is known it is possible to estimate the amounts which can be added without exceeding an IV of 70 in the backfat. IVP in feed mixtures above 160 per day, corresponding to 58 per FUp,* resulted in increasing numbers of pigs with an unacceptable IV of backfat (Fig. 1). When the proportion of polyunsaturated fatty acids in the backfat increases, the storage stability decreases, as does the flavour and taste. However, one has to consider that only part of the pig meat produced is eaten fresh, the rest being processed.

Intramuscular fat (IMF)

Lean meat with a high content of IMF has better sensory properties and higher palatability than meat with a low fat content. IMF in loin has been reduced as the fat content of the carcass has been reduced over the years. According to Bejerholm & Gade (1986) 2.0–2.5% IMF is necessary for a satisfactory eating quality.

In contrast to backfat quality, IMF is strongly influenced by genetics. For example, Duroc has more IMF than other breeds (Barton-Gade, 1987). Castrated males generally have more IMF than

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* FUp = feed unit for pig = Danish feed unit for pigs (7722 kJ NE).

boars and gilts (Barton-Gade, 1987). Taste characteristics were slightly inferior in entire males owing to the lower IMF content. Pigs fed ad libitum had similar levels of IMF as restrictedly fed pigs (Madsen et al., 1983).

Recently Madsen et al. (1991a) compared five protein levels in diets for entire male pigs and females. Increasing protein levels decreased IMF approximately from 2 to 1%. This confirms the earlier results by Madsen et al. (1970) shown in Table 2, although the level was quite different. It was also observed that pigs with high IMF had a paler colour than pigs with lower IMF. As fat contributes to the organoleptic quality of pig products, leanness is not an indicator of the entire eating quality.

Fats and fatty acids have been used to replace energy sources without influencing the lean meat content of carcasses (Mortensen et al., 1983). However, the IMF content of the loin decreased with increasing dietary fat supply (Table 7). This table also includes some results from experiments with rapeseed and oats (Madsen et al., 1990b).

The relationship between the dietary level of linoleic and linolenic acid and the level of IMF seems complicated. Recently Østerballe et al. (1990) carried out an experiment with feeds supplying two levels of C18:2 and three levels of C18:3, and another experiment with sunflower seeds. The results regarding IMF are shown in Table 8.

In vivo (Christensen, 1969; 1970) and in vitro

Table 7. Influence of dietary fat on intramuscular fat (IMF) in the loin (Madsen et al. 1990b)

Animal fat, %	0	4	8	13
IMF, %	2.19	2.09	1.71	1.47
Palm oil, %	0	4	8	13
IMF, %	2.02	1.80	1.63	1.31
Rapeseed, %	0	4	8	12
IMF, %	1.37	1.36	1.35	1.43
% Oats of grain	0	33	67	100
IMF, %				
Conventional oats	1.76	1.50	1.37	1.44
Naked oats	1.65	1.74	1.44	1.47

Table 8. Intramuscular fat (IMF) in the loin in relation to dietary intake of C18:2 and C18:3 or sunflower seed (Østerballe et al. 1990)

|						
C18:2, % of fat	15	15	15	31	31	31
C18:3, % of fat	1.4	3.7	5.9	1.6	3.8	6.0
IMF, %	1.42	1.34	1.30	1.33	1.38	1.70
Sunflower seed, %	0	4	8	12		
IMF, %	1.40	1.52	1.60	1.58		

studies (Christensen, 1975) suggested that intramuscular lipids may be synthesized in skeletal muscle independently of the overall fatty acid synthesis, and that the synthesis may be regulated by different physiological and genetic factors. According to our results the dietary influence on the content of IMF seems very complicated. As IMF is of great importance for meat quality, further experiments must be performed.

Future investigations

The daily gain has increased through the years, so nowadays pigs are less mature at a given slaughterweight than previously. As consumers continue to demand less fat and fat with a specific fatty acid profile, future investigations must be concentrated on utilizing the possibilities of manipulating the fat content and fatty acid composition of individual fat depots. It has been shown that changes can occur as a consequence of dietary variations, but the physiological upper and lower limits of fat amounts and fatty acid composition must also be established from an animal welfare point of view. Furthermore, it must be investigated whether IMF can be deposited indepently of other fat depots. As IMF disappears from the muscles, how do cellular lipids, which are mainly phospholipids and cholesterolesters, influence the meat quality? More research is needed on regulatory factors in fat metabolism of the lean pig.

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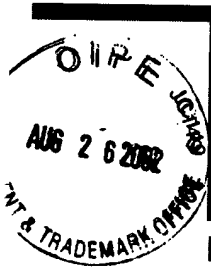
Effect of Feeding OPTIMUM® High Oil Corn on Pellet Quality, Broiler Performance and Carcass Traits

POULTRY

Summary

A study (Collins et al., 1999) was conducted to evaluate broiler chicken live performance and carcass characteristics of broilers fed OPTIMUM* High Oil Corn and typical corn with calculated and determined apparent metabolizable energy (AMEn) content. Treatments consisted of four dietary regimens: 1) typical corn with determined AMEn content; 2) typical corn with calculated AMEn content; 3) OPTIMUM High Oil Corn with determined AMEn content; and 4) OPTIMUM High Oil Corn with calculated AMEn content. A total of 640 day-old male broilers were assigned randomly to each of the four dietary treatments. Each treatment was replicated eight times with 20 birds per floor pen. Broilers were fed a three-phase program, beginning with a starter diet fed as crumbles from one to 21 days. From 21 to 42 days, broilers were fed a pelletized grower diet, and from 42 to 49 days broilers received a pelletized finisher diet. Broiler performance was measured at 1 to 21, 21 to 42 and 42 to 49 days of age, followed by processing at day 49. Corn energy calculation versus direct determination had no apparent impact on broiler live performance or carcass characteristics, with the exception of slight shifts in the levels of palmitic and stearic fatty acids in thigh meat. Adjusted feed-to-gain rations were significantly improved for broilers fed starter diets formulated with OPTIMUM High Oil Corn. In this study, corn type did not significantly affect carcass weight, abdominal fat pad yield, breast meat weight or carcass yield. Additionally, corn type did not significantly affect the body weight of broilers at each stage in the study. The OPTIMUM High Oil Corn diets caused slight, but significant, reductions in levels of palmitic, palmitoleic, oleic and linolenic fatty acids and increases in stearic and linoleic fatty acid levels compared to the fatty acid profile of thigh meat from broilers fed the typical corn-based rations. This likely is due to the contribution of oil from each grain confounded by the degree of fat supplementation required to achieve isocaloric rations. Pellet durability also was evaluated in this study. After 5-minute sieving by Ro-Tap shaker, 10-minute tumble at 50 rpm and 2-minute sieving, pellet durability was improved 15 percent to 20 percent for broiler grower and finisher diets using OPTIMUM High Oil Corn. The OPTIMUM High Oil Corn-based diets contained less added fat than did the typical corn diets, which could account for a portion of the measured improvement with OPTIMUM High Oil Corn.

Objectives

The objectives of this study (Collins et al., 1999) were three fold. First, the study compared broiler chicken live performance and carcass characteristics of broilers fed OPTIMUM High Oil Corn versus typical corn. Second, the study determined the efficacy of estimation of the apparent metabolizable energy (AMEn) by regression equation or by direct determination of AMEn for OPTIMUM High Oil Corn and typical corn. Finally, the study compared pellet durability of OPTIMUM High Oil Corn and typical corn.

Experimental Procedure

Broiler diets were formulated with OPTIMUM High Oil Corn to be isocaloric/isonitrogenous with typical corn-based feeds. The determined AMEn values (Table 1) for the two corns were obtained from a previous study with both broiler chicks and mature cockerels (Collins et al., 1998). The true metabolizable energy (TMEn) values for the OPTIMUM High Oil Corn and typical corn were derived from proximate analysis data which were then utilized in the equation reported by Araba et al., (1998). The calculated AMEn level was then estimated by assuming 95 percent of the TMEn value to represent AMEn (Table 1). Amino acid determinations were conducted on both OPTIMUM High Oil Corn and typical corn prior to diet formulation. The treatments were: 1) typical corn with determined AMEn content; 2) typical corn with calculated AMEn content; 3) OPTIMUM High Oil Corn with determined AMEn content; and 4) OPTIMUM High Oil Corn formulated with calculated AMEn level. The ingredient and estimated nutrient compositions of the test diets are provided in Tables 3, 4, and 5.

A total of 640 day-old male broilers (Ross x Ross 308) were randomly assigned to each of the four dietary treatments. Each treatment was replicated eight times with 20 birds per floor pen. Diets and water were provided ad libitum during the 49-day study. A three phase feeding system was used: starter (1–21 days), grower (21–42 days) and finisher (42–49 days of age). The starter diets were fed as crumbles. The grower and finisher diets were pelletized. Broiler performance was measured at 1–21, 21–42 and 42–49 days of age, followed by processing at day 49. Feeds were sampled from all replicate pens during each feeding phase with assessment of crumble and pellet durability measured according to the ASAE Standard S269.4 (1992).

Table 1. The AMEn Values for Typical Corn and OPTIMUM® High Oil Corn

Corn Source:	Determined AMEn* (kcal/kg) / (kcal/lb)	Calculated AMEn (kcal/kg) / (kcal/lb)
Typical Corn	3330 ± 130 / 1510 ± 59	3320 / 1506
OPTIMUM High Oil Corn	3450 ± 150 / 1565 ± 68	3470 / 1574

*Collins et al. (1998)

Table 2. Analyzed Nutrient Profiles of Typical Corn and OPTIMUM* High Oil Corn*

Nutrient	Typical Corn	OPTIMUM High Oil Corn
Crude Fat, %	3.7	6.7
Crude Protein, %	8.5	9.6
Crude Fiber, %	2.4	2.9
Ash, %	1.2	1.3
Amino Acids		
Lysine, %	0.24	0.27
Methionine, %	0.16	0.19
Cystine, %	0.16	0.21
Threonine, %	0.28	0.35
Tryptophan, %	0.06	0.07
Fatty Acids (% of Total Fatty Acid Profile)		
C16:0	9.8	11.9
C18:0	2.7	2.4
C18:1	23.0	34.8
C18:2	60.8	49.3
C18:3	2.8	0.8

*Standardized to 88 percent Dry Matter

Table 3. Ingredient and Nutrient Composition of Starter (Day 1 to 21) Diets

Ingredients	Typical Corn		OPTIMUM* High Oil Corn	
	Det. AMEn[1]	Calc. AMEn[2]	Det. AMEn[1]	Calc. AMEn[2]
Corn, %	55.41	54.89	58.71	57.76
Soybean Meal, %	33.10	33.15	32.10	32.30
Poultry Fat, %	4.85	5.30	2.60	3.35
Fish Meal Analogue,^ %	3.00	3.00	3.00	3.00
DL-Methionine, %	0.20	0.22	0.15	0.15
L-Lysine HCl, %	—	—	—	—
Other[B]	———————— to 100% ————————			
Analyzed Nutrient Composition[c]				
AMEn, Kcal/kg[D]	3,230	3,230	3,190	3,250
AMEn, Kcal/lb	1,465	1,465	1,447	1,474
Crude Protein, %	22.2	22.6	22.5	23.1
Crude Fat, %	8.1	8.3	7.3	7.6
Crude Fiber, %	2.9	3.1	3.0	3.3
Ash, %	6.6	6.3	6.1	5.7
Lysine, %	1.13	1.17	1.14	1.20
Methionine, %	0.50	0.52	0.48	0.47
Cystine, %	0.30	0.31	0.34	0.34
Threonine, %	0.85	0.87	0.88	0.91
Tryptophan, %	0.27	0.28	0.28	0.28
Analyzed Fatty Acids (% of Total Fatty Acid Profile)				
C16:0	18.8	18.9	16.0	16.7
C16:1	5.1	5.1	2.9	3.3
C18:0	4.9	4.9	3.9	4.1
C18:1	35.3	35.3	35.9	36.6
C18:2	31.6	31.5	37.8	35.7
C18:3	1.6	1.6	1.5	1.4

[1] Det. AMEn = Determined AMEn

[2] Calc. AMEn = Calculated AMEn

^Pro-Pak, H.J. Baker & Bro., Inc. Stamford, Connecticut.

[B] Others = limestone, dicalcium phosphate, salt, coccidostat, vitamin premix and microminerals added to meet requirements.

[c] Nutrients standardized to 88 percent Dry Matter basis.

[D] Determined by cup collection method with mature SCWL roosters (n=6).

Table 4. Ingredient and Nutrient Composition of Grower (Day 21–42) diets

Ingredients	Typical Corn		OPTIMUM® High Oil Corn	
	Det. AMEn	Calc AMEn	Det. AMEn	Calc AMEn
Corn, %	64.31	63.81	68.65	67.55
Soybean Meal, %	26.85	26.90	25.25	25.20
Poultry Fat, %	3.50	4.00	0.80	1.65
Fish Meal Analogue,[A] %	2.00	2.00	2.00	2.00
DL-Methionine, %	0.08	0.08	0.04	0.04
L-Lysine HCl, %	—	—	—	—
Other[B]		to 100%		
Analyzed Nutrient Composition[C]				
AMEn, kcal/kg[D]	3,130	3,230	3,050	3,040
AMEn, kcal/lb	1,420	1,465	1,383	1,379
Crude Protein, %	19.0	19.4	20.0	19.5
Crude Fat, %	6.7	7.0	6.1	6.9
Crude Fiber, %	3.1	3.4	3.1	3.1
Ash, %	5.5	5.3	5.1	5.2
Lysine, %	0.97	1.03	0.98	0.97
Methionine, %	0.36	0.36	0.36	0.37
Cystine, %	0.30	0.31	0.32	0.32
Threonine, %	0.74	0.78	0.79	0.79
Tryptophan, %	0.23	0.23	0.23	0.24
Analyzed Fatty Acids (% of Total Fatty Acid Profile)				
C16:0	17.6	17.4	13.5	15.0
C16:1	4.3	4.3	1.2	2.2
C18:0	4.5	4.4	3.2	3.5
C18:1	33.9	33.7	34.5	35.8
C18:2	35.5	36.1	44.5	40.3
C18:3	1.5	1.5	1.3	1.3

[A]Pro-Pak, H.J. Baker & Bro., Inc. Stamford, Connecticut.

[B]Others = limestone, dicalcium phosphate, salt, coccidostat, vitamin premix and microminerals added to meet requirements.

[C]Nutrients standardized to 88 Percent Dry Matter basis.

[D]Determined by cup collection method with mature SCWL roosters (n=6).

Table 5. Ingredient and Nutrient Composition of Finisher (Day 42–49) diets

Ingredients	Typical Corn		OPTIMUM* High Oil Corn	
	Det. AMEn	Calc AMEn	Det. AMEn	Calc AMEn
Corn, %	69.27	68.58	73.94	73.32
Soybean Meal, %	23.75	23.90	21.70	21.75
Poultry Fat, %	2.75	3.30	—	0.70
Fish Meal Analogue,^ %	1.00	1.00	1.00	1.00
DL-Methionine, %	0.03	0.03	0.01	0.01
L-Lysine HCl, %	0.07	0.07	0.10	0.10
Other[B]		to 100%		
Analyzed Nutrient Composition[c]				
AMEn, kcal/kg[D]	3,280	3,280	3,280	3,310
AMEn, kcal/lb	1,488	1,488	1,488	1,501
Crude Protein, %	17.9	18.1	18.1	18.6
Crude Fat, %	5.9	6.3	5.6	6.1
Crude Fiber, %	2.8	3.0	2.6	2.7
Ash, %	4.4	5.0	4.7	4.6
Lysine, %	0.92	0.92	0.90	0.92
Methionine, %	0.30	0.30	0.32	0.31
Cystine, %	0.28	0.28	0.29	0.31
Threonine, %	0.70	0.69	0.69	0.71
Tryptophan, %	0.22	0.22	0.20	0.21
Analyzed Fatty Acids (% of Total Fatty Acid Profile)				
C16:0	15.9	16.4	12.3	13.3
C16:1	3.3	3.8	0.4	1.0
C18:0	4.1	4.2	2.8	3.0
C18:1	32.3	32.7	33.9	34.6
C18:2	40.8	39.1	47.5	44.9
C18:3	1.5	1.5	1.3	1.3

^Pro-Pak, H.J. Baker & Bro., Inc. Stamford, Connecticuit.

[B]Others = limestone, dicalcium phosphate, salt, coccidostat, vitamin premix, and microminerals added to meet requirements.

[c]Nutrients standardized to 88 percent Dry Matter basis.

[D]Determined by cup collection method with mature SCWL roosters (n=6).

Results

The method of corn energy estimation (calculation versus direct determination) had no apparent impact on broiler live performance. With the exception of slight shifts in the levels of palmitic and stearic fatty acids in thigh meat (Table 7), formulation with AMEn values derived by calculation did not significantly impact carcass characteristics versus formulation with AMEn values from direct determination. As there were no interactions between corn type and method of AMEn determination for any of the other parameters measured, only the corn source information is presented.

Figure 1. Effect of Corn Source on Pellet Durabiltiy[1]
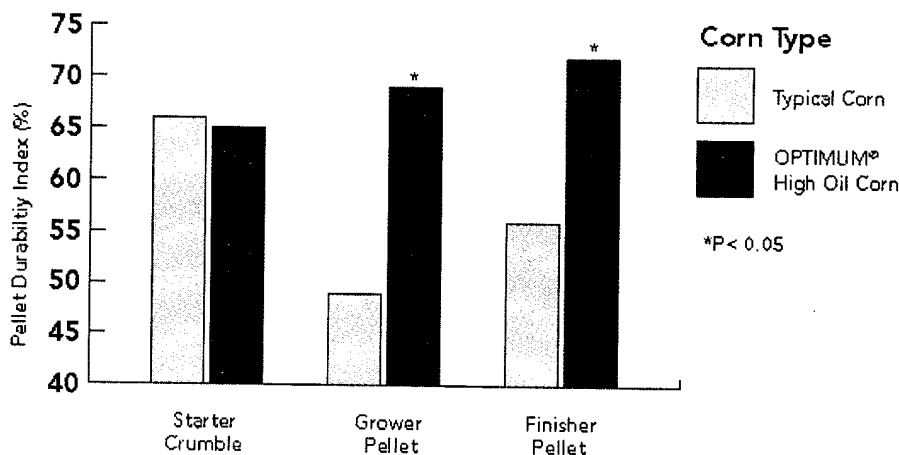
[1] 5 minute sieving by Ro-Tap shaker (Starter = U.S. #12; Grower/Finisher = U.S. #8)
10 minute tumble at 50 rpm, 2 minute sieve (Starter = U.S. # 12; Grower/Finisher = U.S. #8).

Pellet durability (Figure 1) was significantly (P<0.001) greater for broiler grower and finisher diets utilizing the OPTIMUM High Oil Corn. The inclusion of OPTIMUM High Oil Corn, rather than typical corn and added feed fat, improved pellet durability in this study on the order of 15 percent to 20 percent. The OPTIMUM High Oil Corn-based diets, especially the grower and finishers, contained less added fat than did the typical corn-based diets (Tables 4 and 5). This could account for a portion of the measured improvement in pellet quality with OPTIMUM High Oil Corn.

Figure 2. Effect of Corn Source on Broiler Average Body Weight
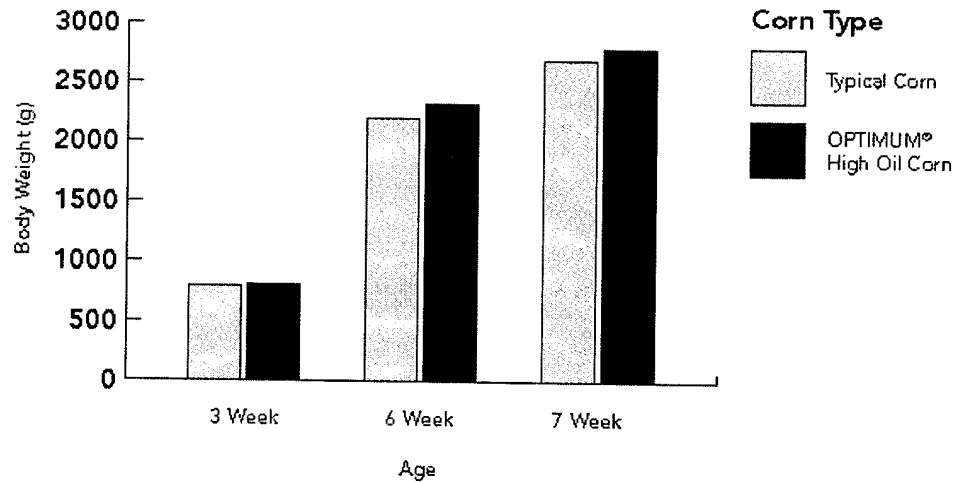
The body weights of broilers were not significantly (P<0.05) influenced by the corn source fed in this study (Figure 2).

Figure 3. Effect of Corn Source on Broiler Feed Efficiency
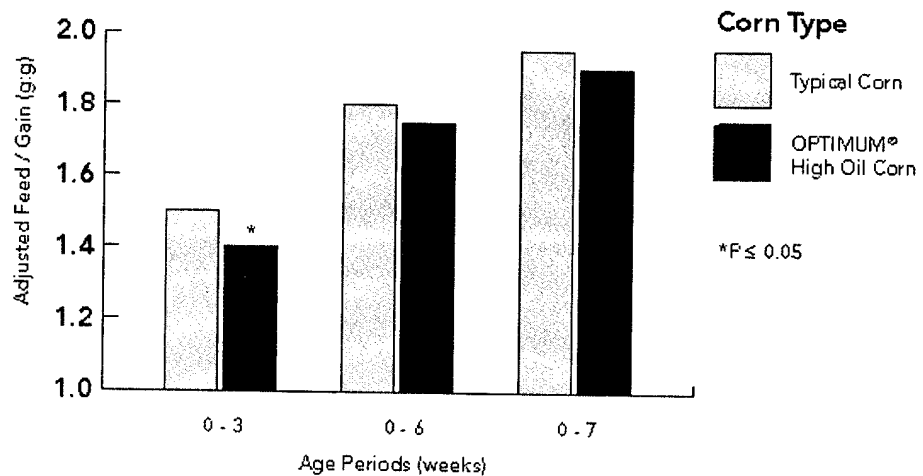
Adjusted feed-to-gain ratios (Figure 3) were significantly (P<0.05) improved for broilers fed starter diets formulated with OPTIMUM High Oil Corn. The consistent, numerical improvements in broiler live performance, as measured by weight gain and feed efficiency, indicate that the energy estimations for the OPTIMUM High Oil Corn may have been slightly low. However, as the broilers' live performance did not differ appreciably when fed the OPTIMUM High Oil Corn and typical corn rations, the relative relationship between the estimated energy values for the two grains was apparently close to synchrony.

Table 6. Effect of Corn Source on Broiler Carcass Traits

Corn Source	Carcass Weight[1] (g)	Fat Pad Weight (g)	Abdominal Fat Pad[2] (%)	Breast Meat Weight (g)	Carcass Yield[3] (%)
OPTIMUM* High Oil Corn	2050	49	2.4	457	69.1
Typical Corn	2041	51	2.5	460	68.9
Pooled SEM	23.4	1.1	0.05	8.5	0.26
Statistical Analyses					
Treatment	NS[4]	NS	NS	NS	NS

[1]Carcass weight includes abdominal fat pad weight.

[2]Abdominal fat pad expressed as percent of carcass weight.

[3]Carcass yield expressed as % of 7 week, full-fed weight.

[4]NS=Not significant at $P<0.05$.

Corn type did not significantly affect carcass weight, abdominal fat pad yield (grams; %), breast meat weight or carcass yield in this study (Table 6). Again, this would indicate the birds did not materially differentiate between the two corn types when the energy levels for OPTIMUM High Oil Corn and typical corn were properly estimated and the dietary formulations altered accordingly.

Table 7. Effect of Corn Source on the Fatty Acid Profiles of Broiler Thigh Meat

	Palmitic C16:0	Palmitoleic C16:1	Stearic C18:0	Oleic[1] C18:1	Linoleic[2] C18:2	Linolenic C18:3
	(% of Total Fatty Acid Profile)					
Corn Source						
OPTIMUM* High Oil Corn	23.0	5.4	6.3	38.7	22.0	0.8
Typical Corn	23.6	7.2	6.0	39.2	19.4	0.9
Formulation Type						
Determined AMEn	23.5	6.2	6.2	38.9	20.5	0.8
Calculated AMEn	23.2	6.4	6.1	39.0	20.8	0.8
Statistical Analyses						
Corn Treatment	***	***	***	***	***	***
Formulation Treatment	*	NS	*	NS	NS	NS
Pooled SEM	0.10	0.05	0.04	0.08	0.15	0.01

*P<0.05
***P<0.001
NS=Not significant at P<0.05
[1]Main effects interaction (P<0.01)
[2]Main effects interaction (P<0.05)

The OPTIMUM High Oil Corn diets caused slight, but significant, reductions in levels of palmitic, palmitoleic, oleic, and linolenic fatty acids and increases in stearic and linoleic fatty acid levels in comparison to the fatty acid profile of thigh meat of broilers fed the typical corn-based rations (Table 7). These alterations in the fatty acid profile of the thigh meat are likely a reflection of the contribution of oil from each grain confounded by the degree of fat supplementation required to achieve isocaloric rations. Indeed, other than slight shifts in the relative levels of stearic and oleic acids, the fatty acid profiles of the thigh meat are very close to what would be predicted from the fatty acid compositions of the grower and finisher rations (Tables 4 and 5).

Conclusions

Based on the results of this experiment, using OPTIMUM High Oil Corn in rations with lower supplemental fat inclusion improved pellet durability compared to typical corn. Additionally, thigh meat fatty acid profiles were significantly influenced by diet. Diets formulated to meet equivalent metabolizable energy and nutrient specifications, regardless of corn source, produce similar results in broiler performance and carcass characteristics. Finally, estimation of the AMEn of OPTIMUM High Oil Corn and typical corn by calculation from proximate analytical data produced equivalent responses in terms of most broiler live performance and carcass traits to direct AMEn determination.

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